Applied Terrestrial Laser Scanner in Active Volcano Crater: Correction to Velocity and Geometry

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Keywords: Laser Scanner, Error Sources, Volcano Environment, Atmospheric Correction

SUMMARY

Terrestrial laser scanner (TLS) was deployed in active crater of Papandayan volcano, West Java, Indonesia. The objective is to analyze influence of volcanic environment into TLS measurement result. Three targets were distributed inside crater with active volcanic gas emission. Targets were placed at difference distances, from 50 to 150 m. Type of TLS used is medium range Leica ScanStation C 10 which has maximum scope of 300 m. Along with TLS measurement, meteorological sensor also recorded temperature, relative humidity and air pressure. Location where three targets were located then substituted by GPS geodetic measurement to get data comparison.

Distance measurement obtained by TLS and GPS then compared. It showed that distance from TLS is shorter than GPS. This is contradictive with our assumption, that TLS will give longer distance due to laser dispersion. However, we interpreted that volcanic gases distorted laser propagation and give false return. The difference of horizontal distance is up to 8 cm for distance ~150 m, while difference of slope distance is smaller. Refraction index was calculated using temperature, humidity and air pressure data and applied for velocity and geometry correction. Temporary result shows that correction only significant for first velocity, while for second velocity and geometry is very small.

This paper introduce only first part of the research where we present preliminary result of volcano environment effect to distance measurement. We are still looking for alternative correction modeling and evaluate method of measurement. But we conclude that active volcanic crater contribute significant error source in TLS measurement. Finding appropriate TLS distance correction is important, because we will use it for volcano deformation monitoring that need very high accuracy.

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1. INTRODUCTION

Terrestrial Laser Scanner (TLS) for active volcano survey has some advantages (Jones,2007), i.e measurement can be conducted from remote area that has no risk for surveyor and less consume time. Mapping with TLS also can reach inaccesible area (crater area for example) and has wider scope area mapping. TLS can detect rapid displacement that can trigered slope and dome collapse. TLS has wider acquisition and give better accuration compare to convensional method.

TLS has wide applied because of its privileges in data acquisition rate, data increment, reflectorless, and can give 3D information from an object surface. In other words, TLS has ability to give high spatial resolution therefor can detect small scale deformation (Tsakiri et.al, 2006).

But TLS also has some error sources that related with survey method, instrument, scanned object and environmental effects. These errors effect data quality of TLS and decrease quality of 3D model as final result. Effect of these error sources can be reduce by select appropriate survey method, apply appropriate correction and perform calibration (Reshetyuk, 2009).

2. ENVIRONMENTAL ERROR IN TLS MEASUREMENT

Environmental errors is function of temperature, atmospheric, interferred radiation and movement distortion. Internal temperature from instrument will expand one part of tripod so that distorted data. In addition to the equipment temperature, the temperature of the scanned object will affect the data. If the object has a high temperature, background radiation from the surface will degrade the signal to noise ratio so that measurement precision will be low. Atmospheric variations which include temperature, humidity and pressure will affect the index of refraction and propagation of electromagnetic energy waves. In other words, the laser speed is influenced by the density of air. Some types of scanner has been completed with software tool for correction of refraction which contains some standard atmospheric parameters. But if the measurements conducted outside the standard atmospheric condition will require some additional corrections.

Lasers work on very short wavelengths. Precision of measurement is probably influenced by external radiation, for example by a strong external illumination source. In this case can be solved by installing optical filter so only certain wave and frequency can be accepted by the equipment.

At the time of scanning, the scanner will experience the vibrations that cause a shift in the equipment, therefor the scanner must be mounted on a stable place to minimize the vibration. The scanner was equipped with a new type of two-axis compensator to minimize the movement of the scanner during the scanning process.

Ingensand (2006) concluded that error of the coordinate system (S_{xyz}) from a point cloud produced by TLS is a function of:

- distance (D); which correlated with atmospheric parameters- Reflectance / reflectivity of the object; affect the signal to noise ratio (SNR)
- Ambient light; affect SNR
- Angle of incidence beam (θ)
- Wavelength; correlated with surface roughness of rock and produce spots/speckles (white noise)
- Color of the object surface
- Object surface roughness
- Geometry object; can cause multipath effects

Bonforte et al (2011) stated that the volcanic rock of black porous lava has poor reflectivity characteristics. From these statements it concluded that the nature and object types have different responses to TLS.

Boehler and Marbs (2002) states that TLS measurements in areas where presence of dust or vapors/gases may cause an error that resembles edge effects. It happens because laser propagation velocity changes due to variations in temperature and pressure. Edge effects occur if only some part of object edge is reflected, while others are behind or around the scanned object.

Grantham et al (1997) conducted a study on atmospheric effect into TLS measurement results and found a pixel dropout phenomenon, a condition in which the laser pulse is too weak to trigger the receiver, so recorded as zero value or maximum value of the pixel. This phenomenon is associated with attenuation of the laser.
Grantham et al (1997) also concluded the phenomenon of false returns, which are laser dispersed by rain water droplets, aerosols, water vapor or dust particles suspended in the air, and strong enough to trigger the receiver. Most of the transmitted laser energy reflected by particles and partly by the object's surface. These conditions generate multiple return pulse and contaminate the data thus complicate the identification process of the scanned object.

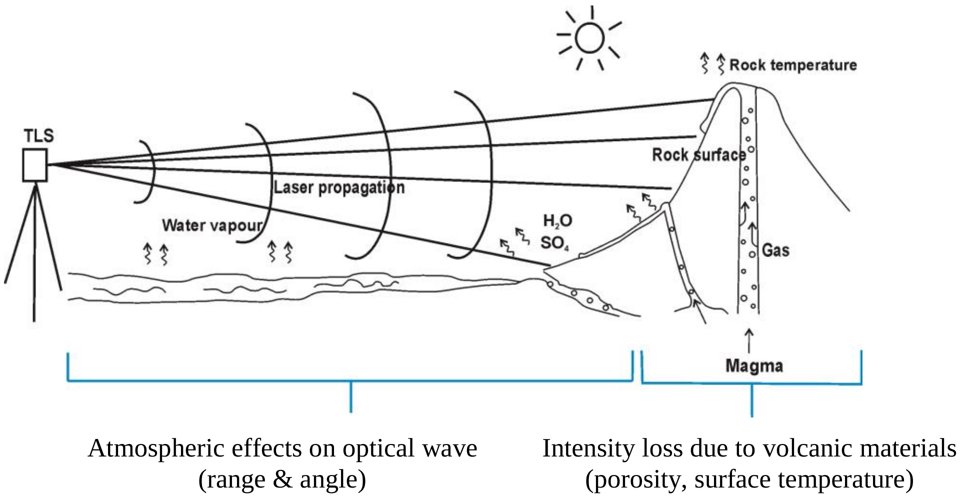


Figure 1. Illustration of volcano’s environmental effects into TLS measurement.

3. DATA AND METHOD

3.1 Experiment design

Three targets were distributed inside crater with active volcanic gas emission. Targets were placed at difference distances, from 50 to 150 m. Type of TLS used is medium range Leica ScanStation C10 which has maximum scope of 300 m. Along with TLS measurement, meteorological sensor also recorded temperature, relative humidity and air pressure. Location where three targets were located then substituted by GPS geodetic measurement to get data comparison. GPS measurement use Topcon GR3 as rover at the crater, and Trimble 4000 SSI as reference station at Papandayan Volcano Observatory that located about 8 km from the crater. TNDD TR-73U was use to record temperature, humidity and air pressure. One unit of TNDD was placed each at target and TLS stand station.

Picture	Description
	Dominant activity of suphuric gases (SO_4), temperature of gas holes 106-220°C, no vegetation covering, loose volcanic rocks, white-grey-green color of altered volcanic rocks. Rocks temperature near gas holes is ~70°C.

Figure 2. Location of experiment

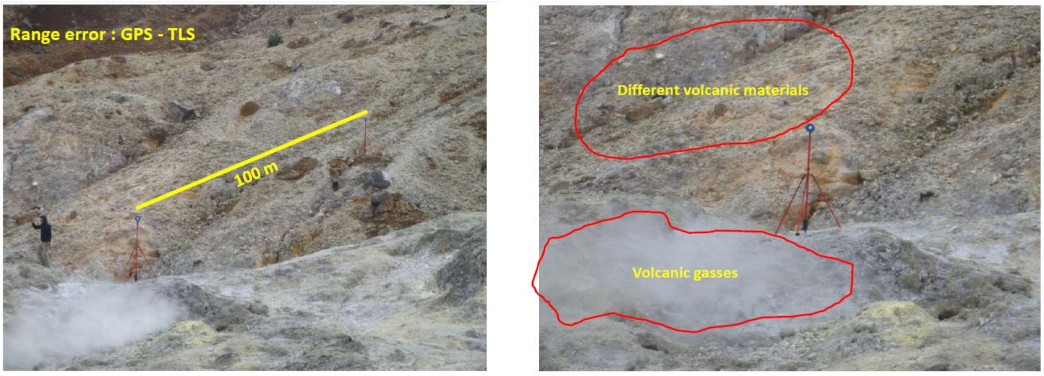


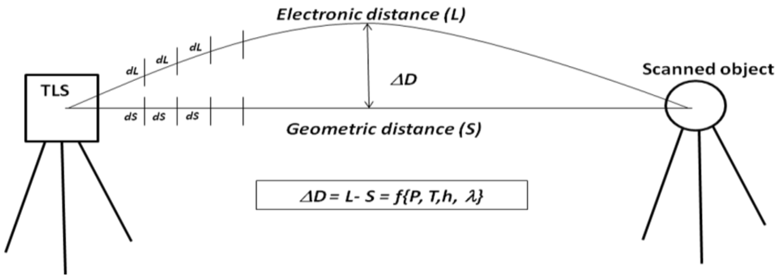
Figure 3. Placement of targets of A~50 and B~100 m.

3.2 Correction model

Several mathematical models have been applied for point cloud processing, including the Least Square 3D surface matching (Monserrat and Crosetto, 2008), mathematic morphology (Medina et al, 2011), K-means algorithm (Medina et al, 2011) and random sampling consensus (Fischler and Bolles, 1981). These models have limitations since they were applied to man-made objects with controlled parameters so they are not applicable for different conditions. This research tries to make physical models using mathematics as a tool, thus resulting model can be applied generally.

Ciddor (1996) has made a mathematical model to determine the refractive index of air. He formulated some constants to calculate the refractive index of air (N), based on refractive index of dry component (N_h) and water vapor component (N_w). Although this model does not involve contamination of the atmosphere (such as aerosol, absorption effects, and others), but could be applied because it has been take into account all known factors. Ciddor also concluded that for 350Nm> λ> 1300nm this model is valid for all atmospheric conditions. Rueger (1990) have modeled distance correction for electro-optical distance meter instrument (EDM) in which the working principle is similar with TLS. Formulation of distance correction by Rueger (1990) involving a reference refractive index (n_{REF}) which is function of wavelength modulation (λ_{MOD}) and frequency of equiment (f_{MOD}).

This research will apply both models above. Calculations by these models then analyzed and evaluated to formulate a new model according to data measurement. Expected new models can accommodate some parameters that have not been included in existing models.



$$\Delta D = c_d k_d(\lambda)\int \frac{P}{T} dl + c_v k_v(\lambda)\int \frac{e}{T} dl + k$$

Figure 4. Atmospheric effects on TLS observation and proposed simple analytical solution.

Until now, almost all type of TLS using the ISO standard atmospheric parameters, which is 15^{o}C air temperature and air pressure 1013.25 hPa. If TLS work in conditions outside this atmospheric parameters it will result error, for example 10° C air temperature difference or change in air pressure of 35 hPa will generate an error of 1 mm at a distance of 100 m. Leica scan station that use in this study has ability to achieve an accuracy within 4 mm and 6 mm for a distance of 1-50 m (Leica Geo System, 2011). This error has no significant effect on the measurement of short or medium distances, but for measurements with a longer distance it required atmospheric correction parameters. TLS measurements at 2000 m altitude at mountain areas with air temperature 10°C/100m and changes in air pressure temperature 0.65 hPa /100 m will result in an error of 8mm /100m (Quintero et al, 2008).

4. RESULT AND DISCUSSION

4.1 GPS measurement result

Short baseline GPS campaign at each targets was deployed and its results use to compare the distance, with the assumption that GPS measurement is not affected by trophospheric bias due data reduction process (differencing) that eliminate most of the effects (Abidin et al, 2011). GPS data was processed using Leica GeoOffice v.8. Baseline calculation between TLS stand and each targets give results as seen in table 1 below:

Table 1. Results of GPS baseline in meter. TA,TB and TC refers to number of target.

Baseline	Slope distance	Horizontal distance
BASE-TA	52.3006	52.3193
BASE-TB	98.6192	98.4931
BASE-TC	149.2783	147.9143

4.2 TLS Measurement result

TA was measured 50 times, TB 49 times while TC 11 times. TC has more less measurement due to visible difficulties. Results from each measurement is fluctuated and showed in figure 5 below while distance error (compare to GPS) is in figure 6.

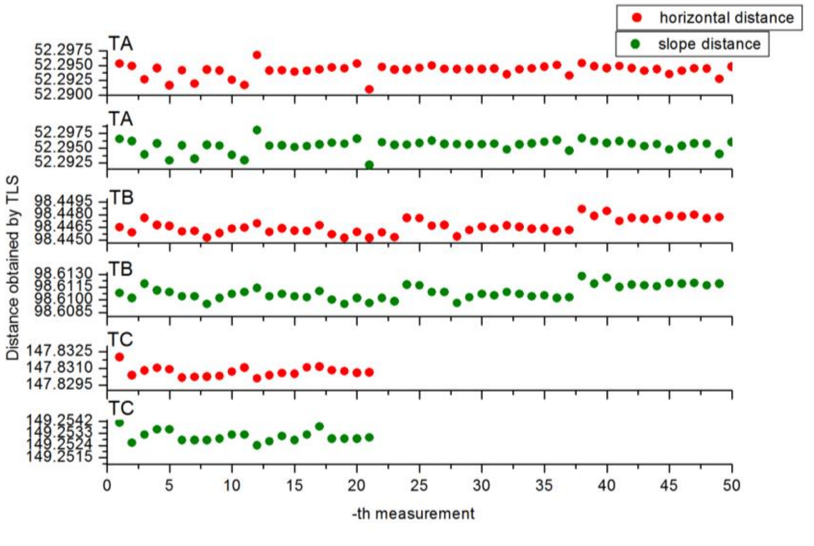


Figure 5. Results of TLS measurement for each target.

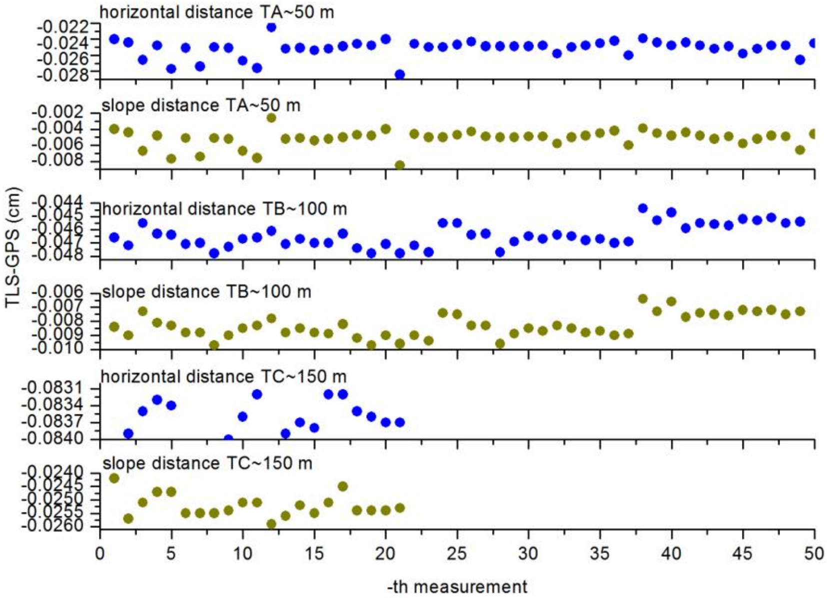


Figure 6. Distance difference of TLS and GPS.

4.3 Local atmospheric data

Recording of air temperature (T), relative humidity (h) and air pressure (p) at TLS stand and target is shown in Figure 7 and 8. Temperatures at TLS stands has range of 15.3-23.6 ° C, 83-53% of relative humidity, and air pressure of 785.1-783.2 hPa. Temperatures at the targets has range 14.7-24.2 ° C, 87-43% of relative humidity, and air pressure of 783.1-782.1 hPa. Range of Thp values beetwen TLS and targets is not much different, and although its fluctuates during the measurement period but showed the same pattern. Corrrelation of distance measurement and atmospheric parameters (using Tph at the targets) is showed in figure 9, 10 and 11.

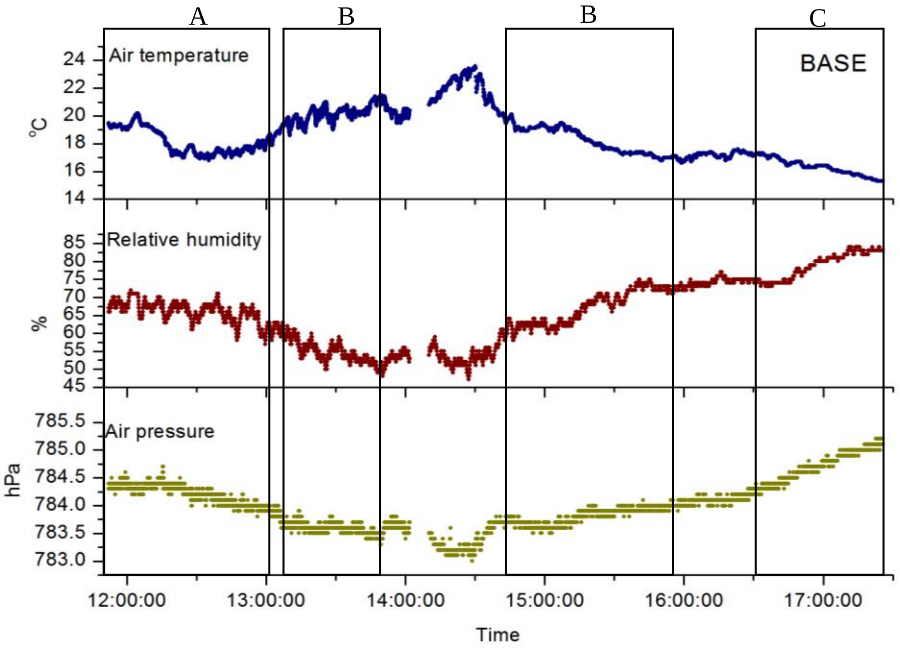


Figure 7 . Thp at TLS stand during the measurements, data recorded every 5 second.

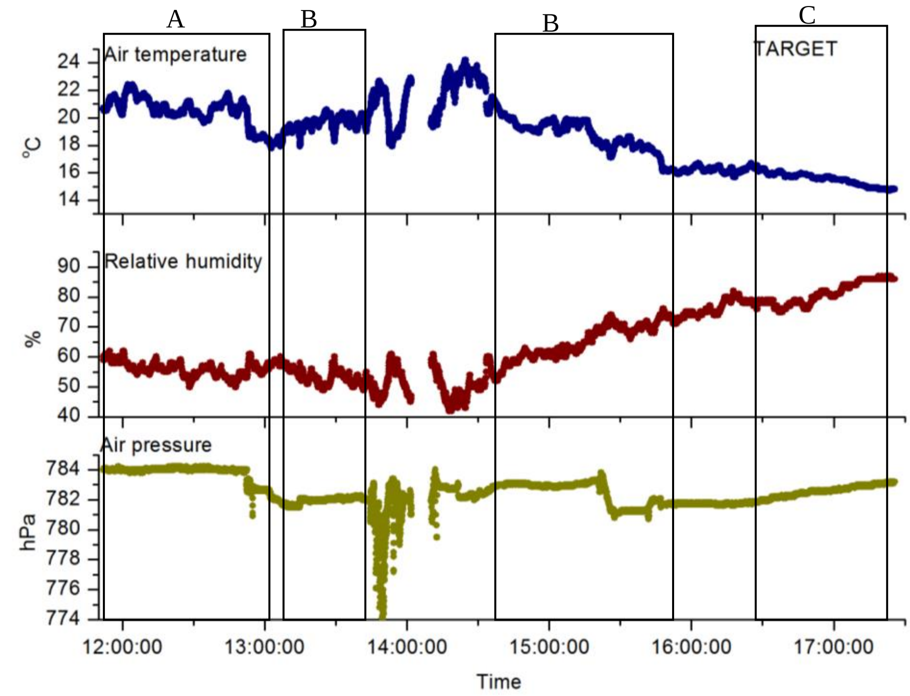


Figure 8. Thp at targets during the measurements, data recorded every 5 second. Data during TB measurement was disturbed due to downloading process.

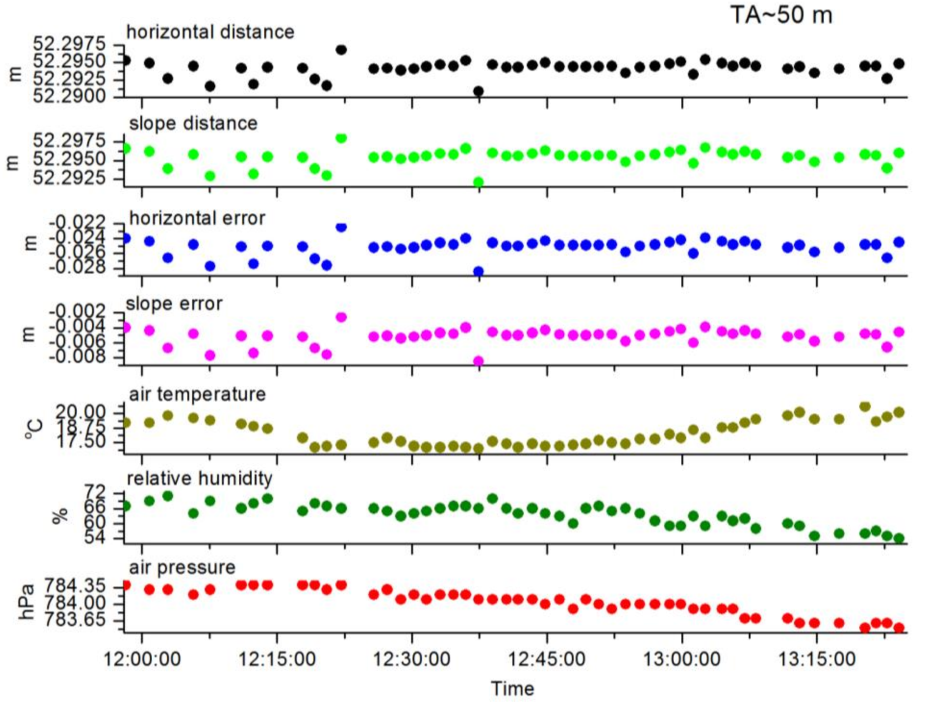


Figure 9. Distance results, error and atmospheric paramaters for TA ~ 50 m.

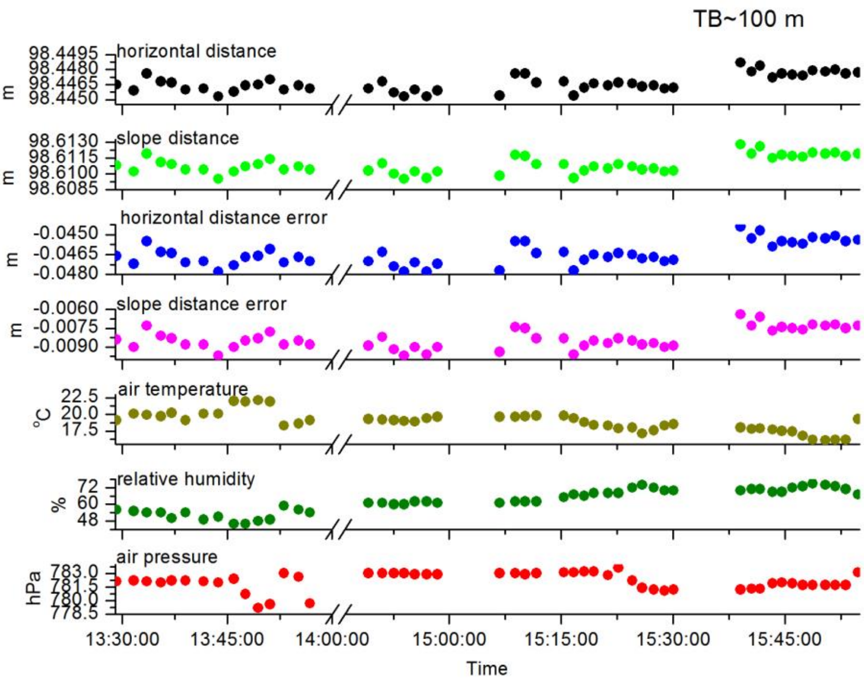


Figure 10. Distance results, error and atmospheric paramaters for TB ~ 100 m.

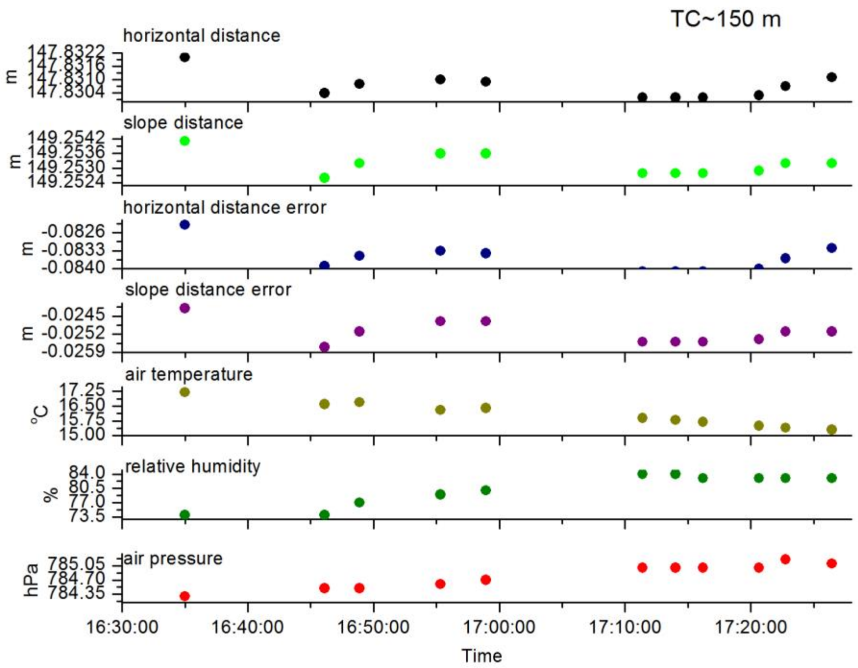


Figure 11. Distance results, error and atmospheric paramaters for TC ~ 150 m.

4.4 Application of correction model

Horizontal and slope distance from TLS corrected using first velocity correction (K1), second velocity correction (K2) and geometry correction (K3) as formulated by Rueger (1990). Results of these corrections is summarized at table 2,3 and figure 12,13.

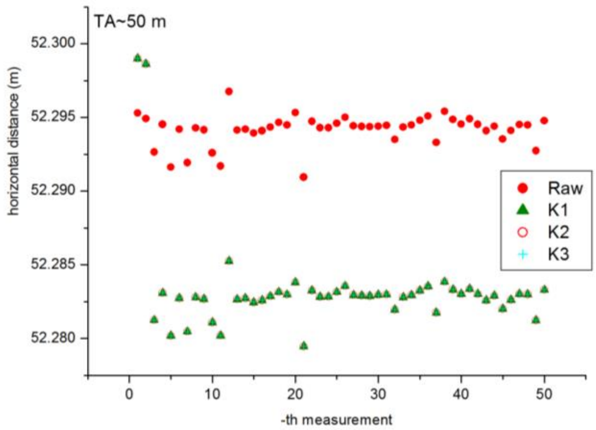
Table 2. Horizontal distance correction.

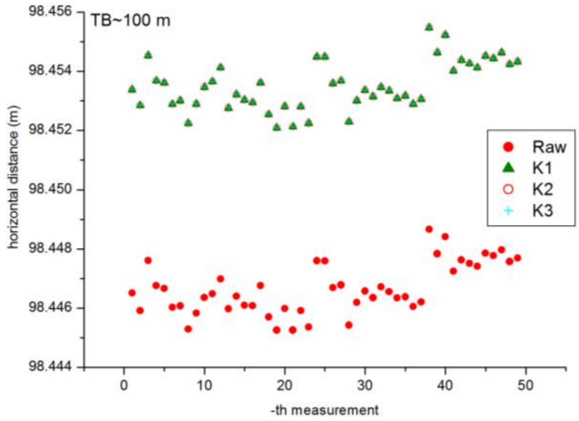
	A~50 m Average correction (m)	B~100 m Average correction (m)	C~150 m Average correction (m)
K1	$-1.149\text{x}10^{-2}$	$6.846\text{x}10^{-3}$	$9.825\text{x}10^{-3}$
K2	$-4.479\text{x}10^{-11}$	$-1.714\text{x}10^{-10}$	$5.020\text{x}10^{-15}$
K3	$-1.092\text{x}10^{-7}$	$-6.678\text{x}10^{-10}$	$-5.867\text{x}10^{-13}$

Tabel 3. Slope distance correction.

	A~50 m Average correction (m)	B~100 m Average correction (m)	C~150 m Average correction (m)
K1	$-1.149\text{x}10^{-2}$	$6.857\text{x}10^{-3}$	$9.920\text{x}10^{-3}$
K2	$-4.480\text{x}10^{-11}$	$-1.722\text{x}10^{-10}$	$5.069\text{x}10^{-15}$
K3	$-1.092\text{x}10^{-7}$	$-6.711\text{x}10^{-10}$	$-6.038\text{x}10^{-13}$

Plotting graph of initial measurement and correction (Figure 12 and 13) shows that for TA~50 m results shorter distance, while correction for TB~100 m and TC ~150 m show a longer distance. K1 correction shows significant value at each distance, even reaching a fraction of cm at TA~50 m. But K2 and K3 correction showed a very small value which is interpreted due to involvement of curvature spheroid variable (*R*, radius of the earth) in calculation, while the distance measured in this experiment is relatively short. Very small value causes the value of K2 and K3 overlaid at K1.





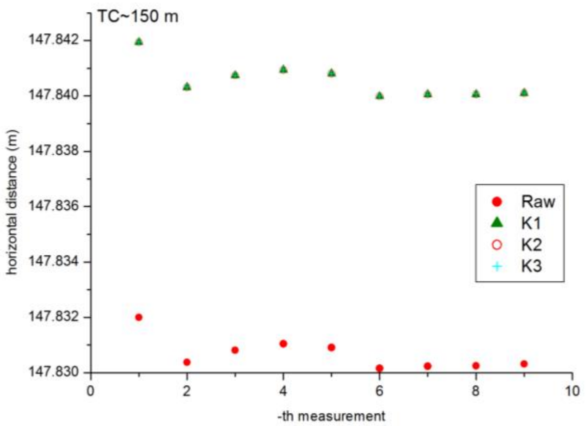
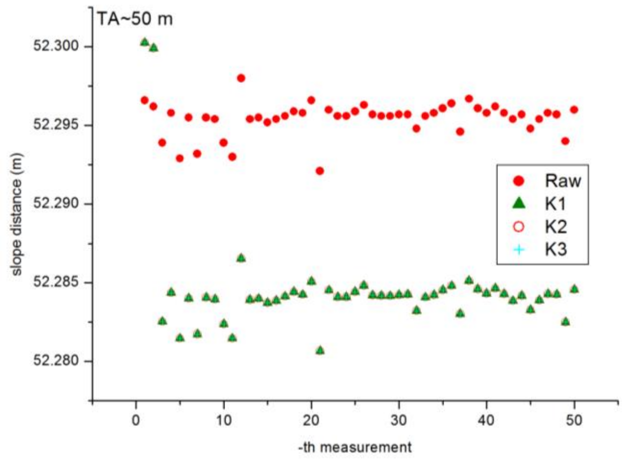
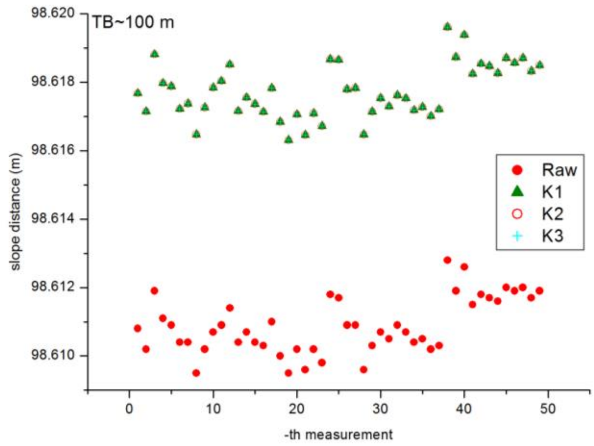


Figure 12. Horizontal distance correction for TA~50 m, TB~100 m, and TC~150 m.





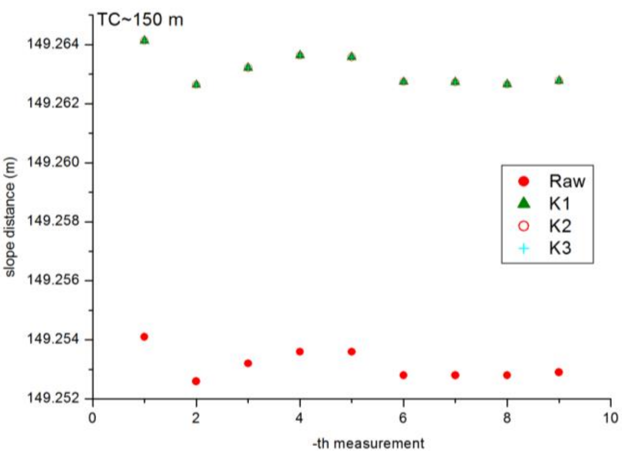


Figure 12. Slope distance correction for TA~50 m, TB~100 m, and TC~150 m.

Preliminary results of this research do not show the expected one, especially in correction results. K2 and K3 is not significant, possible due to some factors: short baseline, small elevation gradients, and insignificant Thp value between target and TLS stand. Correction models of Rueger (1990) using Thp standard, and only involves CO_2 in the air. In this research, gas component is more varied (volcanic gases generally consist of a compound H_2O, N_2, CH_4, CO, CO_2, SO_2, H_2S, HCl, NH_3 and H_2O) that have different characteristics, so they have not been accommodated in this model.

To test these possibilities, further experiments need to be done mostly to improve the method. A comparison experiments in non volcanic environment need to carried out and applied the same correction.

5. CONCLUSION

From preliminary analysis we drawn some conclusions as follows:

1) Activity of volcanic gases and local atmospheric conditions of active volcano crater effect distance value obtained by TLS measurement, and has significant error value along with increasing of distance.
2) Correction of distance measurement only significant for first velocity correction, while second velocity correction and geometric correction is not significant.

6. FUTURE WORKS

As further step to this research we will apply Zenith Hydrostatic Delay (Saastamoinen, 1972). Correction between these models then compared and reviewed to determine the most suitable model. We will also evaluate design of measurement and conduct the same method at normal/non volcanic environment. Result from volcanic and normal environment will be compare to see some solutions. Looking for another correction model also essential to get better result or if necessary create new correction formula.

REFERENCES

Abidin, H.Z., Jones, A., Kahar, J. (2011): Survei dengan GPS, Penerbit ITB.

Boehler, W., dan Marbs, A. (2006): *Investigating Laser Scanner Accuracy*, Institute for Spatial Information and Surveying Technology, University of Applied Sciences, Mainz, Germany.

Bonforte, A., Calvagn, F., Puglisi, G, dan Sacareno, B. (2011): Terrestrial Laser Scanning (TLS) Over Volcanic Areas : Experiments on Vesuvius, Stromboli and Vulcano (Italy), *Geophysical Research abstracts*, Vol. 13, EGU2011-11657,2011, EGU General Assembly 2011.

Ciddor, P.E. (1996): Refractive index of air: new equations for the visible and near infrared, *Appl. Optics* **35**, 1566-1573

Fischler, M.A dan Bolles, R.C (1981): Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography. *Communications of the ACM*, 24(6):381–395.

Granthamn, J.W., Stargardt, C.D., Dungey, C., dan Meidunas, E. (1997): Laser Radar in adverse weather, *SPIE proceedings*, Vol. 3065, pp 84-93.

Ingensand, H. (2006): Metrological Aspect in Terrestrial Laser Scanning Technology, Institute of Geodesy and Photogrammetry, ETH Zurich, *3rd IAG/12th FIG Symposium*, Baden.

Jones, Lee D. (2007): *The Application of Terrestrial LIDAR to Volcano Monitoring – An Example from The Montserrat Volcano Observatory*, British Geological Surveys, Keyworth, Nottingham.

Medina, A.S, J Martínez, J., Buffara-Antunes, A.F, Arias, P., González-Jorge, H. (2011): An Approach To Extracting Façade Features Using The Intensity Value Of Terrestrial Laser Scanner With Mathematical Morphology**.** *Proceedings of the 28th ISARC*, Seoul, Korea**.** Pages 552-557.
Monserrat, O. dan Crosetto, M. (2008): Deformation measurement using terrestrial laser scanning data and least square 3D matching. *ISPRS Journal of Photogrammetry and Remote Sensing* 63 (2008) 142-154.
Quintero, M.S., Genechten, B.V., Bruyne, M.D., Ronald, P., Hankar, M., dan Barnes, S. (2008): *Theory and Practice on Terrestrial Laser Scanning, Training Material Based on Practical Applications*, Vlaams Leonardo da Vinci Agenschap.
Reshetyuk, Y. (2009): Terrestrial laser scanning error sources, self-calibration and direct georeferencing. *VDM Verlag Dr. Muller*, Germany.
Rueger, J.M., (1990): Electronic distance measurement. An Introduction, 3rd totally revised edn., *Springer Verlag*, Berlin.
Torge, W. (2002): Geodesy 3rd edition, De Gruyter Graduate.
Tsakiri, M., Lichti, D., dan Pfeifer, N. (2006): Terrestrial Laser Scanning for Deformation Monitoring, *3rd IAG/12th FIG Symposium*, Baden.
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