Assessment on topographic mapping using total station and terrestrial laser scanner technology (case study: Kiara Payung area, Sumedang)

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Abstract. The unique capability of Terrestrial Laser Scanner (TLS) technology in observing a considerable amount of any object above the Earth’s surface opens an interesting opportunity to produce fast and reliable topographic maps. However, the use of TLS for topographic mapping should be thoroughly investigated in many aspects, including the accuracy of the observed data, the field acquisition, human resource, data processing, cost, and time acquisition. The purpose of this research is to carry out preliminary investigations. The methodology of this research consists of a reconnaissance survey, measurement planning, TLS, Total station, and Global Positioning System (GPS) data acquisition, georeferenced, filtering, 3D (Dimension) modeling and map visualization. Several aspects of the result compared with the conventional techniques by using Electronic Total Station (ETS). The results of this research show that the average error of measurements is approximately 4 mm and the detail level of the generated Digital Elevation Model (DEM) is pretty good, as it is indicated by a huge number of total point clouds (223,460 points) with the point density of about 0.25 m on optimum scanning area. TLS is suitable for a fast mapping area with a considerably large scale (1:300). In addition, based on time and human resources for mapping in the same area, the topographic mapping by TLS requires lesser time and human resources than mapping by the other methods such as ETS. The only disadvantage of using TLS is its price is still costly. As a preliminary conclusion, the TLS is more suitable to be used on high accuracy mapping, such as the reconstruction of the building, cut and fill survey, documentation of historical building.

1. Introduction
Mapping is a map-making process that represents part of the Earth’s surface in two dimensions projected coordinates using a particular scale that is printed into a paper [1]. In line with technological developments, the current end product of mapping activities is no longer an ordinary two-dimensional printed map, but also can be represented as a three-dimensional digital map. As a result, this digital map could be easily adjusted to any further additional topographic data.

There are several methods of topographical mapping with various technologies being used, including the extra-terrestrial method using photogrammetric techniques, remote sensing satellites, and geodetic satellites [2]. Other than extra-terrestrial methods, there is a terrestrial method using theodolite, Electronic Total Station (ETS) and Terrestrial Laser Scanner (TLS). Each of these methods has its own advantages and drawbacks. For example, extra-terrestrial mapping can cover wider area in a relatively
short amount of time, however, it is not effective for topographical mapping in the forest area due to its position accuracy reduced by the vegetation. On the other hand, terrestrial mapping is done at a very close distance to the object thus it can have a higher level of detail, however, it requires a relatively longer time of data acquisition to survey a large area.

TLS technology is expected to overcome this drawback when we used a conventional terrestrial mapping technology like ETS. TLS is able to obtain the position of the object points (point clouds) in a huge amount and high precision in a relatively short time. This method can be applied in many applications such as: in mining, architecture, civil engineering, crime investigation, and for geological purposes [3, 4, 5, 6].

Although TLS has been widely used in several applications, most surveyors in Indonesia are afraid to use TLS technology due to its complexity and cost. This study will discuss the performance of topographic mapping using TLS when compared to the results of mapping using ETS technology, both in terms of the position accuracy and the mapping activity processes (time, effort and cost). We choose Kiara Payung, Sumedang Regency, Indonesia as our case study due to its orography condition and vegetation.

2. Data and method

2.1. Data

2.1.1. Preparation
Preparation of topographic mapping using TLS in this study includes preliminary surveys, measurement planning, and preparation of tools. A preliminary survey was conducted to determine the condition of the measurement area in order to determine the position of the measurement station, target position, mobilization path, the object to be scanned, and possible measurement constraints. Measurement planning is carried out after the preliminary survey, including planning for the station and target placement, planning of the measurement schedule, the number of HR needed, and the equipment to be used. The numbers of measurement stations used in this study are 44 set-ups and 148 targets divided on three days of measurement. Whereas the preparation of the equipment is done a day before the mapping activity is carried out by checking the equipment completeness and charging the TLS battery to be used.

2.1.2. Data acquisition
In summary, data acquisition using TLS lasted for three days with 1 surveyor and 3 helpers. On the first day, we were able to scan with 11 different set-ups using 46 targets. The measurement data of the first day will be registered using the target-to-target method and tied to the mapping control point by establishing the target just above the control point. On the next day, we ended by scanned with 14 set-ups and 44 targets. The measurement data for the first and second days were registered using a cloud-to-cloud method. The last day ended with 19 set-ups and 48 targets. Registration of third-day measurement data used target-to-target method, while to combine with measurement data from another day, we used the cloud-to-cloud method. Some of the sets on the third-day measurement were not used later due to low laser penetration to the ground caused by vegetation (Fig. 1).
2.2. Method

Similar to ETS, TLS measure angle and distance to estimate the coordinate of an object. Most of the TLS instruments measure distance using time-of-flight measurements [7]. It requires a precise clock to measure the amount of time needed ($\Delta t$) for the pulse to travel from the sensor to the object and reflected back to the sensor. By knowing the speed of light ($c$), distance can be obtained by:

$$ D = \frac{c \Delta t}{2} $$

Instead of observing and record the object manually, a motor is added into the instrument so that a typical commercial TLS can rotate 360 degrees horizontally 270 degrees vertically. This configuration providing a full coverage 3D position of the surrounding area in a relatively short time.

By using a single scan of TLS measurements, an incomplete point is observed due to shadowing effects. The shadowing effects create data missing behind the objects. Therefore, to create a complete point cloud, several scans from a different view angle are needed.

These sets of scans have their own orientation that requires further procedures to make a complete point cloud. This procedure is called registration. The orientation of at least one set scan is needed to be fixed, thus, the other set of scans orientation is adjusted to the fixed orientation by using several techniques, such as point-to-point coordinate transformation or manual adjustment by giving a translation and rotation parameter. Georeferencing process could be implemented into the point cloud data if we need a true coordinate on the produced map.

Some of the scanned objects, such as trees, marsh and any vegetation cover may not be used or visualized in the produced map. Therefore, we need to apply filtering procedures. Filtering can also be done manually or using an automatic algorithm. In general, the workflow used in this research can be seen in Figure 2.

**Figure 1.** The situation surrounding the station 38 looks from the west (a), looks from the south (b), looks from the east (c), and looks from the north (d).
3. Data and method

3.1. Data processing

Data processing from the data acquisition phase using TLS consists of the registration process, filtering, surfacing, and object identification and contour line drawing. The registration process is carried out on the Cyclone software with seven registration stages. First, registration of measurement data for the first day using the target-to-target method with an average registration error of 4 mm. Second, registration of measurement data for the second day using the target-to-target method with an average registration error of 4 mm. Third, registration of the third-day measurement data uses the target-to-target method with an average registration error of 4 mm. Fourth, registration of the third-day measurement data in the area around the campground hall uses the target-to-target method with an average registration error of 3 mm.

Fifth, registration of measurement data on the first and second days using the cloud-to-cloud method with an average registration error of 4 mm. Sixth, registration of the first-second measurement data that has been registered with the third-day measurement data registered using the cloud-to-cloud method with an average registration error of 5 mm. And the seventh, registration of the first-second-third day measurement data with measurement data around the campground hall uses the target-to-target method with an average registration error of 7 mm so that the average registration error of the entire measurement data is 4 mm.
The indirect georeferencing method carried out in the data processing by introducing the known coordinate of control points. Therefore, the local coordinate system which is observed by the TLS can be transformed into a global coordinate system like Universal Transverse Mercator (UTM) zone 48S.

The next stage is the process of filtering or eliminating points that are not considered necessary for the DEM generation or topographic maps. Filtering in this study is divided into two stages, the first is filtering which leaves large trees with tree diameters between 20 cm - 60 cm with results as in Figure 3. The number of measurement points before the filtering process is 282,202,656 points and after the process the first stage filtering left a point of 143,644,133 points.

**Figure 3.** Point cloud which represents trees coverage of mapping area.

The second stage of the filtering process is removing all points that are above the ground so that the remaining points are only points that are considered as representations of the ground. The points are identified based on their vertical position, the point with the lowest vertical position of the collection point is defined as the point representing the surface of the ground. At this stage, a uniform density of 25 cm is also carried out so that it reduces the number of points quite significant for the next process. The results of this process can be seen in Figure 4. The number of points after this process is 223,660 points.

**Figure 4.** Point cloud that represents the land surface in the mapping area.
The next process is meshing, which forms the surface of the measurement points so that the data becomes continuous. The result of the meshing process is the DEM (Digital Elevation Model) which is a model that reflects the surface of the ground in the mapping area. The DEM is formed by connecting measurement points into Triangulated Irregular Network (TIN). The formed DEM is shown in Fig. 5 which refers to an ellipsoid height reference system. A green polygon bounds the high vegetation areas.

The contour interval used is 1 m because there is a fairly steep area or slope of more than 45°. Roads, river, building and distribution of large trees as well as the classification of land cover also situated in the produced map. The cartography of these details is in accordance with national regulation of thematic map. The generated topographic map is shown in Figure 6.

![Figure 5. Topographical map using TLS.](image)

### 3.2. Distance measurement validation

To assess TLS accuracy performance, we compare the distance derived from the TLS with another measuring instrument as a validation. We used a distance meter and measuring tape as a validator. 8 samples are made with an average difference is 7 mm. Table 1 shows the differences for each sample.

| Sample | Difference (mm) |
|--------|-----------------|
| Sample 1 | 5.2 |
| Sample 2 | 4.7 |
| Sample 3 | 5.8 |
| Sample 4 | 6.1 |
| Sample 5 | 4.9 |
| Sample 6 | 6.3 |
| Sample 7 | 5.5 |
| Sample 8 | 5.9 |

It could be seen in Table 1 that our validator has accuracy about 5 mm as indicated by the maximum observed distance differences from both our validator instrument. The differences between TLS and our validation is likely due to the difference between the first and last pick point in our point cloud. Although TLS can collect a high density of points to cover an object, a non-uniform point spacing might occur due to incident angle from the set-up point.
Table 1. Validated distance measurement data.

| ID | Observed distance (meter) | Differences (meter) |
|----|---------------------------|---------------------|
|    | TLS | Distance meter | Measuring tape |    |
| 1  | 2.479 | 2.49 | 2.498 | 0.015 |
| 2  | 0.506 | 0.51 | 0.51 | 0.004 |
| 3  | 0.526 | 0.52 | 0.515 | 0.008 |
| 4  | 2.482 | 2.49 | 2.498 | 0.012 |
| 5  | 2.491 | 2.485 | 2.485 | 0.006 |
| 6  | 1.929 | 1.933 | 1.928 | 0.001 |
| 7  | 1.937 | 1.931 | 1.93 | 0.006 |
| 8  | 6.489 | 6.484 | 6.48 | 0.007 |

Mean difference 0.007

3.3. Comparison of TLS and ETS digital elevation model

A comparison of DEM generated using ETS and TLS can be seen in Fig. 7. These DEMs are generated by connecting the points to become a Triangulated Irregular Network (TIN). In areas bounded by a green polygon show a low number of measurement points in both ETS dan TLS data due to high existing vegetation in this area.

It could be seen from Fig. 7 that the DEM derived using TLS shows a higher level of detail to represent the Earth's surface. TLS technology formed about 223,660 points within three days of data acquisition, while ETS technology formed about 1159 points within six days of data acquisition. The difference in the point density for both technologies can be also seen from the formed Triangular Net, as shown in Figure 8.

![Figure 6. DEM generated from ETS measurement (a) and DEM generated from TLS measurement (b)](image)
A comparison of the height or elevation is also carried out by subtracting the DEM of TLS with the DEM of ETS. The height difference varies from 0 to 7 meters. This high value occurs in an area where a high density of vegetation is found. We also made a comparison along with two profile as shown in Figure. 10.

![Figure 7. TIN from measurement data using ETS (a) and TIN from TLS (b)](image)

![Figure 8. The elevation difference between DEM generated by TLS and ETS, the green line shows the profile to be further compared.](image)
Figure 9. Comparison of two profiles.

The profile line of measurement data using TLS tends to always be above the ETS profile line with the elevation difference in the range of 0 cm - 30 cm. This is likely due to the unpenetrated laser to the ground. Almost in the entire mapping area is covered by vegetation like grass. The other possibility is due to the interpolated height in the meshing step for ETS data is not represent the true surface due to the less point density on the ETS method.

3.4. Comparison of coordinates, distance, and height difference

The coordinate system used in ETS and TLS results data is the UTM zone 48S projection coordinate system with a geodetic system height (ellipsoid). Coordinate comparisons carried out on objects that are quite clearly identified both from the measurement data using ETS and TLS data, the object is a water bath and a crossroads. Data on the comparison of coordinates and distances are shown in Table 2.

The minimum difference is at cistern point (2), which is almost no difference, this is due to the position of the point is close to the TLS measurement station. In such a condition, it can be identified and located close to the mapping control point so that the effect of propagation error is small.

The maximum difference is at the branching point with a difference in position on the Y (North) axis of 1 m and the difference in distance from the control point is 0.5 m. This can be caused by the propagation of coordinate errors during georeferencing because the road branching points are far from the mapping control point, namely the northern part of the mapping area while the mapping control point is only in the southern part of the mapping area. However, it can also be caused by a mismatch of measurement points or uncertainties in the position of the line representing the path between the ETS data and the TLS data.
### Table 2. Data comparison of object position on measurement results using ETS and TLS.

| Object Being Compared         | ETS (m)        | TLS (m)        | Difference (m) |
|-------------------------------|----------------|----------------|----------------|
| Cistern Coordinate (1)        |                |                |                |
| E                             | 805.043,503    | 805.043,519    | 0.016          |
| N                             | 9.237.062,352  | 9.237.062,394  | 0.042          |
| H                             | 1.011,271      | 1.011,411      | 0.140          |
| Distance from KY1             | 8,956          | 9,001          | 0.045          |
| Cistern Coordinate (2)        |                |                |                |
| E                             | 805.040,021    | 805.040,021    | 0.000          |
| N                             | 9.237.074,164  | 9.237.074,164  | 0.000          |
| H                             | 1.012,423      | 1.012,423      | 0.000          |
| Distance from KY1             | 20,292         | 20,292         | 0.000          |
| Distance from KY1             | 20,292         | 20,292         | 0.000          |
| Cistern’s length              | 12,368         | 12,320         | 0.048          |
| Coordinate of Road Branching Point |            |                |                |
| E                             | 804.747,408    | 804.748,120    | 0.712          |
| N                             | 9.237.474,449  | 9.237.475,502  | 1.053          |
| H                             | 1.004,000      | 1.004,118      | 0.118          |

#### 3.5. Other comparisons

Other comparisons are in the forms of the measurement process and data processing procedures for both mapping methods using ETS and using TLS. Table 3 shows comparative data in the process of measuring and processing data using both ETS and TLS.

Based on Table 3, measurements using TLS are superior in terms of measurement time and required human resources, but for the estimation of TLS costs, it costs far more than ETS. This will be proportional to the number of points that can be produced by each tool, at the same time ETS is only able to measure several points while TLS can measure thousands or even hundreds of thousands of points so that it can directly represent the surface of the object being measured. The disadvantage of topographic mapping using TLS, in our case, is not all points represent the surface due to some vegetation cover.

In the TLS data processing phase, filtering took a considerable amount of time, due to this process requires a manual interpretation to select and identify the objects needed for the next process (tree identification). Whereas the measurement data using ETS only binds the measurement points to the frame and cartographic processes.

### Table 3. Other comparisons are related to field measurements and processing of data from ETS and TLS results.

#### Data Acquisition

| Parameters               | ETS                | TLS                |
|--------------------------|--------------------|--------------------|
| Length of Time           | 6 Days             | 3 Days             |
| Human Resource (HR)      | 6 Personnel (two teams) | 5 Personnel      |
| Renting Costs            | Rp 250,000,- perday | Rp11,000,000,- perday |

#### Data Processing

| Parameters               | ETS                | TLS                |
|--------------------------|--------------------|--------------------|
| Data Processing          | Reference frame data processing | Data registration |
4. Conclusions
The conclusions of this research are as follows:

- Topographic maps for a 12.8 ha area with a scale of 1: 1000 on property owned by ITB-Jatinangor in the area of Kiara Payung, Sumedang Regency mapped using Terrestrial Laser Scanner has a total average registration error of 4 mm.
- Digital Elevation Model (DEM) from measurement data using Terrestrial Laser Scanner in the mapping area was generated using Triangulated Irregular Network (TIN) having the majority of the difference in elevation in the range 0 m to 1 m with DEM from measurement data using Electronic Total Station and scattered evenly distributed throughout the mapping area with a minimum difference of 0 m and a maximum of 7 m in areas with high vegetation.
- Terrestrial mapping methods using Terrestrial Laser Scanner technology generates a product that is more representative of the three-dimensional map or modeled objects and can produce maps of very large scale (1: 300 for medium scanning resolution) in shorter measurement times and resources fewer humans than mapping using Electronic Total Station technology. But in terms of the cost of mapping using TLS, it is far more expensive than mapping using ETS, generally, TLS is used in jobs that require high accuracy in a relatively fast time.

5. References
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