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Monitoring geometric properties of an existing forest road using airborne Lidar data

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Abstract

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Accurate information about geometric properties of a forest road is essential for the sustainable forestry and transportation safety. In this study the ability of airborne Lidar in detecting vertical and horizontal profiles and cross section elements of a forest road was investigated in a deciduous forest of Hyrcanian zone. Moreover, Lidar-derived road data was compared with field surveyed data by Leica Total Station device. The results indicated that the average error of Lidar in assessing vertical and horizontal profiles of the existing road was 0.57 m and 4.9°, respectively. The average error of Lidar in detecting the roadbed was 0.78 m. Lidar had an average error of 1.36% in assessing the longitudinal gradient. Based on findings of this study it was concluded that geometric properties of existing forest roads can be monitored rapidly under dense tree canopy using high-resolution Lidar data and without field survey.

Keywords: vertical profile; cross section; horizontal profiles; total station; roadbed

Access to accurate information about geometric properties of a forest road is essential for the sustainable forestry and transportation management (Coffin 2007; Robinson et al. 2010; Sidle, Ziegler 2012). The geometric properties of a road including slope gradient, travel width and curve radius can be monitored using the three-dimensional (3D) auto-detection technique (Hinz, Baumgartner 2003; Türetken et al. 2013; Xiao et al. 2017). The auto-detection technique of a road on geospatial images was started more than thirty years ago (Mena, Malpica 2005; Amo et al. 2006; Mayer et al. 2006). This technique applies a high resolution spatial image (smaller than 1 m) in detecting geometry, topology, texture and especially colour (Lacoste et al. 2005; Grote et al. 2012; Mnih, Hinton 2012; Ziems et al. 2012).

Lidar is a light detection and ranging technology which can measure the distances by sending laser and receiving the reflex (David et al. 2009; He et al. 2017). This technology can provide 3D information from the terrain and its surface objects. The aerial laser scanner is used to provide data for different goals particularly in the forest applications such as forest road designing and evaluation. The topographic data extracted from airborne Lidar sensors have two important advantages in detecting forest roads. The first is the ability of finding terrain points under the closed forest canopy cover to produce a high-resolution digital terrain model (DTM) and the second is the ability to detect the vertical distribution of objects in the terrain through the 3D process of Lidar point cloud. Therefore, nowadays Lidar data is frequently used in forest parameter monitoring. Ferraz et al. (2016) detected road geometry parameters in a forested environment. They found that forest road geometries were accurately retrieved with few errors.

Craven and Wing (2014) used the airborne Lidar to investigate the characteristics of existing forest roads under different conditions of canopy cover. The vertical and horizontal error of Lidar data in assessing the central alignment of existing road was 0.28 and 1.21 m, respectively. The standard deviation of longitudinal gradient and the radius of horizontal curve were 1% and 3.17 m, respectively. White et al. (2010) produced the map of forest roads under the canopy cover using the field survey and Lidar data. Results indicated that the maximum error of mapping by Lidar was 1.5 m. Besides, the maximum error in detecting the road gradient was 0.53%. In recent years, accurate DTM has made tremendous changes in recording and analysing terrain elevation variations, and therefore engineers have been able to obtain updated information on geometric plans and linear terrain such as roads in a short time for a wide area of the region. Thus, using this technique will reduce the amount of time spent in the forestry project preparation. The purpose of this study was to detect and control the geometric properties of a part of forest road in district one of Bahramnia forestry plan using surveying vertical profile, cross section and horizontal profile by Leica Total Station (Leica TPS800; Leica Geosystems, Switzerland) and airborne Lidar.

MATERIAL AND METHODS

Study area. The study area is located in Bahramnia forestry plan in northern Iran (36°44'N, 54°23'E) at 650 m a.s.l. The managed forest area covers 1,713.3 ha. It is a mixed deciduous forest which has been established on brown forest soil with mostly sandstone as bedrock. Clay-loam silty texture and worn stones are spread around the region. The climate is moderate and moist. The mean annual precipitation is varying from 528 to 817 mm and it is the lowest in July and August (Fig. 1). The length of studied forest roads in district one was 555 m. These roads were constructed in 1989. The tree species are *Parrotia persica* (de Candolle) C.A. Meyer, *Carpinus betulus* Linnaeus, *Fagus orientalis* Lipsky, *Quercus castaneifolia* C.A. Meyer and *Zelkova carpinifolia* (Pallas) C. Koch. Based on data taken from the forest management plan, the mean tree density per hectare was 214.92 and the canopy cover was 75–85%.

Processing Lidar data. Lidar data were taken by RIEGL LMS-Q5600 laser scanning system (RIEGL Laser Measurement Systems GmbH, Austria) mounted to an aircraft planned by the Rayan Naghsheh Company in October 2011 before leaves fall from trees. More information about Lidar is shown in Table 1. The point clouds were classified as first, last and intermediate pulses using RiProcess software (Version 1.5.8, 2015). Preprocessing was done on original Lidar data to remove random errors and then an accurate and high-resolution digital elevation model (DEM) was produced from the first and last pulses by the Kraus and Pfeiffer algorithm with spatial resolution of 1 m (Craven, Wing 2014; Hui et al. 2016). At the next step, the cloud points of a small part of DEM around the selected road were recalled in AutoCAD Civil 3D (Version 2013) and then the cloud points were converted to a surface. The vertical profile, cross section and horizontal profile were created from the surface using a triangulated irregular network (TIN) algorithm. TIN was

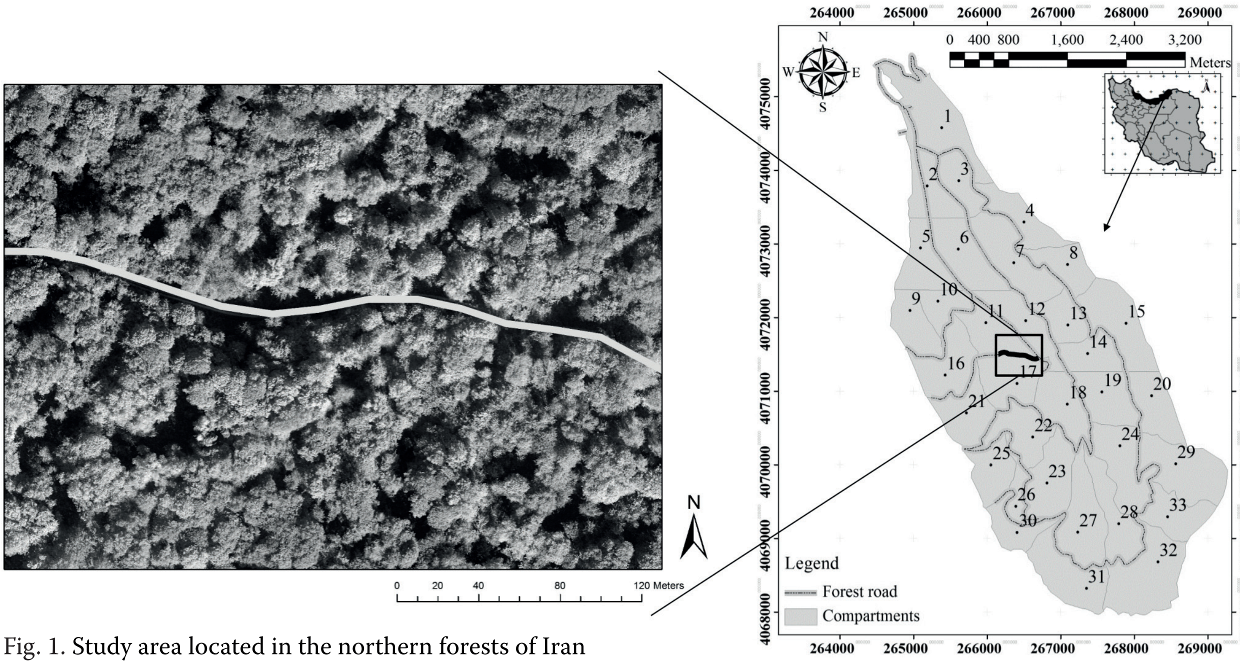

Fig. 1. Study area located in the northern forests of Iran

Table 1. Some characteristics of RIEGL LMS-Q5600 laser scanning system (RIEGL Laser Measurement Systems GmbH, Austria)

Accuracy (cm)	Precision (cm)	Laser wavelength (nm)	Scan angle range (°)	Laser pulse speed (KRZ)	Density of point clouds on the ground (points per m^2)
20	10	NIR (1069)	±22.5, ±30	≤ 240	4

NIR – near infrared, KRZ – Krzana

used to create DEM. The vertical profile and horizontal profile were extracted every 20 m. All cross sections perpendicular to the road were extracted on the same position as was the total station used. Sections were taken over 10 m from each side of the centreline.

Field surveying by Leica Total Station. Total station surveying was used to perform horizontal and vertical measurements in reference to a Universal Transverse Mercator grid system. Vertical profile, cross section and horizontal profile of a forest road with the length of 555 m were taken for special points and every 20 m by Leica Total Station. Components used in total station surveying were prism, prism pole, electronic notebook, computer interface, batteries and radios. Leica job and stations were set for surveying using the program menu. All the point coordinates of a track that were recorded by a differential geographical position system were added to the device. Then, the device was levelled in each of the stations and the data were collected. The primary function was to measure slope distance, vertical angle and horizontal angle from a setup point to a foresight point. Total station used a modulated near-infrared light emitting diode which sends a beam from the instrument to a prism. The prism reflects this beam back to the instrument and total station measures the length of time of this reflection. Data were extracted by Leica Geo Office software (Version 8.4, 2014) and the profiles were designed in Land Surveying Software (Version 11.11, 2013).

Accuracy measurements. In this study mean difference (MD) was applied to measure the accuracy of the Lidar measurements. It can be computed from the deviations between true and measured elevation values. Leica Total Station measurements were considered as true data. MD was computed using Eq. 1:

$$\mathrm{MD}=\frac{\sum_{ij=1}^{n}\left|X_i-Y_j\right|}{n} \qquad (1)$$

where:

X_i – Lidar measurements,

Y_j – Leica Total Station measurements,

n – total number of measurements.

RESULTS

Results showed that with use of the Lidar data, the accuracy of vertical profile and horizontal profile increased as extracted point spacing is reduced to 1 m (Fig. 2). Fig. 3 showed that the horizontal profile taken by Leica Total Station has some sharp turns, which makes it difficult for curve designing.

The map of cross sections taken by Leica Total Station and Lidar is illustrated in Fig. 4. In Fig. 5a, the elevations inferred from Lidar topography agree well with profile elevations taken in the field survey by Leica Total Station. Horizontal accuracies were also assessed point by point along the field surveyed centreline of the roads using Lidar and the Leica Total Station-derived azimuths (Fig. 5b). A highly reliable roadbed data was obtained by the Lidar-derived road position (Fig. 5c).

Results of the present study showed that the average error of Lidar in assessing the vertical profile

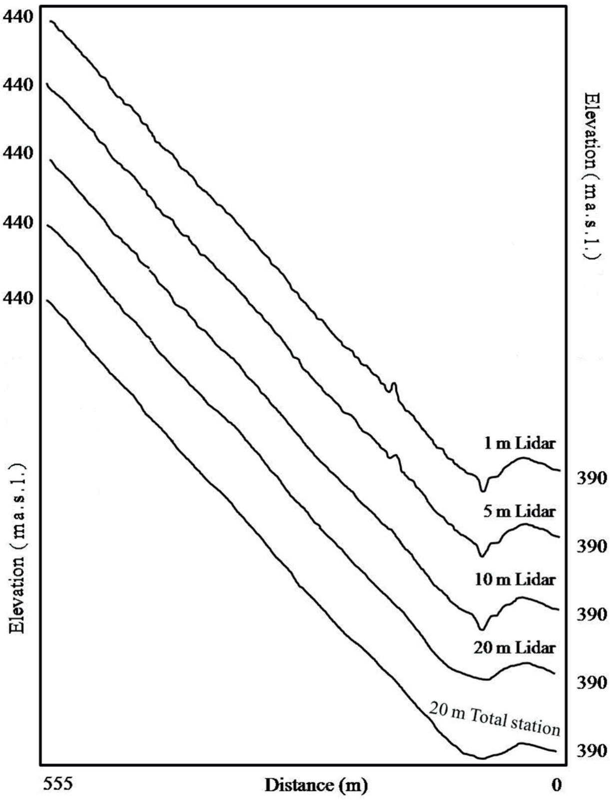

Fig. 2. Vertical profile produced by Lidar and Leica Total Station (Leica TPS800; Leica Geosystems, Switzerland)

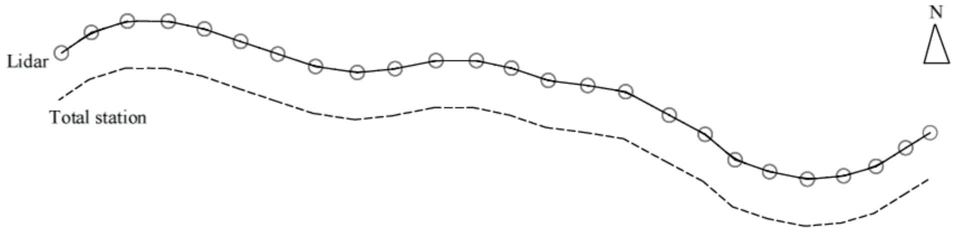

Fig. 3. Horizontal profiles taken by Lidar and Leica Total Station (Leica TPS800; Leica Geosystems, Switzerland), circles represent surveyed points on the road

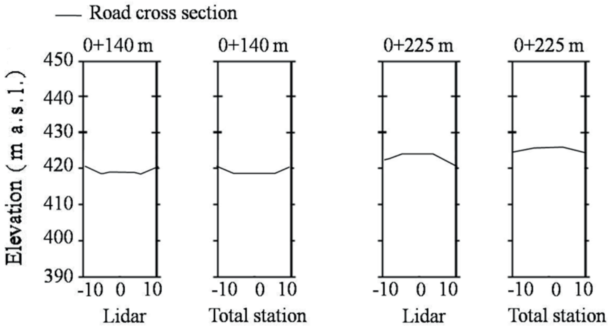

Fig. 4. Samples of cross sections taken by Leica Total Station (Leica TPS800; Leica Geosystems, Switzerland) and Lidar every 20 m

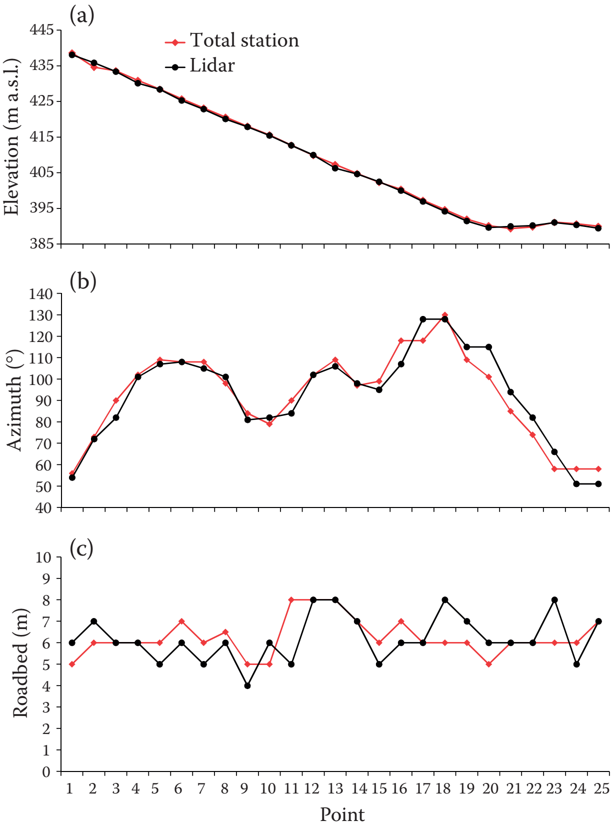

Fig. 5. Comparison of point by point elevation (a), azimuth (b), roadbed (c) data taken by Lidar and Leica Total Station (Leica TPS800; Leica Geosystems, Switzerland)

was 0.57 m. In addition, the horizontal profile of the existing road was detected with an error of 4.9°. The average error of Lidar in assessing the roadbed was 0.78 m (Table 2).

DISCUSSION

Preparing elevation data is the first step to produce DEM. Digital model has more accuracy if the density of elevation data is high. Airborne Lidar can play an important role in collecting 3D data from railways, power lines, pipelines, dams and roads. Detecting an urban, rural and forest road network is one of the abilities of Lidar (Clode et al. 2007). Results showed that with the use of Lidar data, the accuracy of vertical profile and horizontal profile increased as the extracted point spacing is reduced to 1 m. Depending on the spatial resolution, some areas are difficult to identify due to minimal canopy penetration. If the lowest Lidar return or high resolution DEM in an area is assumed, then the resulting topographic surface contains gullies, earth slumps, or hummocky topography will be easily identified since it will not look like a real ground surface. The horizontal profile taken by Leica Total Station has some sharp turns, which makes it difficult for curve designing. This problem is avoided by Lidar. Some researchers reported that Lidar data is a secure source in estimating the longitudinal gradient and position of the central alignment of road, but there is a mistake in determining the smaller radius curve (Craven, Wing 2014; Hui et al. 2016).

Results of the present study showed that the average error of Lidar in assessing the vertical profile was 0.57 m. In addition, the horizontal profile of the existing road was detected with an error of 4.9°. Similar finding was reported by Craven and Wing (2014). They found that the vertical and horizontal

Table 2. Estimated vertical and horizontal error of Lidar

Geometric properties	Longitudinal gradient (%)	Roadbed (m)	Vertical deviation (m)	Horizontal deviation (°)
Mean difference	1.36	0.78	0.57	4.9

error of Lidar data in assessing the road central line was 0.28 and 1.21 m, respectively. In forest, Lidar accuracy is the majority assessed for vertical accuracies. Horizontal accuracies are difficult to obtain because the Lidar pulses must be returned from distinct features that can be found in the field and measured (Craven, Wing 2014) and this can be the reason for an error in detecting the horizontal profile of this study. Reutebuch et al. (2003) tested airborne Lidar using 347 elevation points collected via Leica Total Station and Global Positioning System across four canopy classes: clear-cut, lightly thinned, heavily thinned, and uncut. Results showed the uncut site had the largest average error. Gomes-Pereira and Janssen (1999) reported a range of vertical error values (0.08–0.15 m) on flat ground and larger errors on sloped ground (0.25–0.38 m).

In this study the average error of Lidar in assessing the roadbed was 0.78 m. Besides, Lidar had an average error of 1.36% in assessing the longitudinal gradient. This result was in agreement with the findings of other researchers who showed the average error of 1% (Craven, Wing 2014) and 0.53% (White et al. 2010) in detecting the longitudinal gradient by Lidar. In another research the accuracy of Lidar in detecting the forest roads was estimated to be 82% (Espinoza, Owens 2007). Lidar produces these errors where a dense canopy prevents all Lidar pulses from reaching the ground and therefore it can provide misleading information. Moreover, a standard tool for measuring the existing road longitudinal gradient, as opposed to a total station, is a clinometer. It was proved that the Lidar estimates of road slopes are within the accuracy of a clinometer (Sessions et al. 2010). Azizi et al. (2014) developed a three-step classification approach for forest road extraction utilizing Lidar data. Results showed that the ±1.3 m positional accuracy for road features is a substantial improvement compared with the accuracy (±10 m) of traditional data sources used to plot roads on the 1:25,000 topographic maps in Iran. We compared profile elevations along a selected road profile.

CONCLUSIONS

The results of this research indicated that the geometric properties of existing forest roads can be monitored rapidly under dense tree canopy using high-resolution Lidar data. With the use of Lidar the accuracy of vertical profile and horizontal profile increased as the extracted point spacing is reduced to 1 m. Moreover, the horizontal profile taken by Leica Total Station has some sharp turns, which makes it difficult for curve designing. This problem is avoided by Lidar. The accuracy of road mapping using Lidar can be used for a quantitative terrain analysis without the need for ground reconnaissance in the field. Lidar provides the ability to monitor existing roads on large scales in denied areas where the ground survey is difficult.

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