LOW-COST LIDAR APPLICATION ON UNMANNED AERIAL VEHICLE FOR ROAD SURFACE SURVEY: FEASIBILITY STUDY

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ABSTRACT In this paper, we evaluate the performance of the outdoor low-cost LiDAR with time-of-flight type, that widely used in the robot developer communities, for the road surface survey. The point cloud data are used to construct the digital elevation model (DEM) of the road surface. DEM is used to analyze the accuracy and identification ability of the road surface defection. From the experiments in laboratory for evaluating the limitation of the sensor, we found that DEM accuracy depends on platform elevation and tilt angle. The results show that it can measure the small pits with depth less than 5 cm when the sensor platform is lower than 10 m for concrete surface. For all road surfaces, the standard deviation of elevation measurement increases linearly when measure lower than 6 m and increases rapidly for the elevation beyond 10 m. However, it increases slightly with incident angle. Moreover, the measurement failure is small at the range below 6-m elevation for all incident angles and all three surfaces (concrete, old asphalt, and uncompressed asphalt). This implies that the UAV should fly just above the overpass and use LiDAR to survey the road surface. With this height, this sensor can be done for the surface survey of 10-m width road.

1. INTRODUCTION

The road surface condition is valuable information both economic and social development. Due to most economic and social development are expanded with the assistance of road quality. This information can help the related organization to plan preventive maintenance that affects the quality of life. The knowledge of road surface condition can be used to plan the best travel route which saves expense and time, moreover, it can help to reduce the road accident. Such information can be obtained from several survey methods. The LiDAR sensor is one of the high-performance surveying because it gives the point cloud data which is similar to the 3D model of the road surface. The accuracy and number of the point cloud data depend on the quality of the LiDAR sensor; however, the surveying grade LiDAR is expensive. Therefore, it cannot be widely applied in general road survey. In this paper, we study the feasibility to apply the low-cost LiDAR for UAV road survey. The performance of low-cost LiDAR is evaluated in the laboratory.

2. LIDAR PRINCIPLE AND RELATED WORKS

Light Detection and Ranging (LiDAR) is a similar technology to Radar, using a laser instead of a radio wave. The principal methods are triangular method and time of flight method. The distance from a sensor to an object is measured by Time of Flight (ToF) method. This method is a measurement of the distance from a sensor to an object, based on the time difference between the emission of a signal and its return to the sensor, after being reflected by an object. By using infrared light, we can ensure less signal disturbance and easier distinction from natural ambient light, resulting in the best performing distance sensors. There are many factors worsen the reflected beam. Inverse-square law widens the reflected beam. The reflected observable cross-section depends on the incident angle. The large incident angle makes small reflected observable cross-section. Surface reflectivity is also a crucial factor. For our work, it is unacceptable to improve surface reflectivity. The LiDAR works well on a diffuse reflection surface since the reflected beam disperses uniformly. On the specular surface, LiDAR probably fails to detect the reflected beam unless viewing from the normal.

LiDAR technology had been applied to several applications such as survey the power line (Gong et al., 2006), construct the building footprints (Zhang et al., 2006), observe the Seacliff volumetric change (Young and Ashford, 2006), etc. Moreover, it also applied to many objectives to survey the road environment i.e. extract the road markings (Yang et al., 2012), detect the road edge (Zhang, 2010), etc.

Low-cost LiDAR is a popular sensor that wildly uses in the robot developer communities. It is used to generate a data point cloud for scanning its surround environment which is one way to acquire 3D information of environment (Wulf and Wagner 2003). Ramer et al. (Ramer et al. 2015) used the low-cost LiDAR combining with other low-cost sensors for localization and mapping of indoor applications.

2. LIDAR TEST PROCEDURES

In this section, the procedures to evaluate the performance of low-cost LiDAR sensor will be described. We use “LiDAR lite V3” model from GarminTM (see Figure 1) as a representative of the low-cost LiDAR with ToF type. The key details of this sensor is shown in Table 1. For cost and safety reasons, the experiment is done horizontally rather than upright. The LiDAR is stationary, and the tested surface on a plate with adjustable incident angle is moveable along a track. The experiment was done indoor and the tested surface was not heated. As a result of this, air refraction index above tested surface did not rise and fall irregularly. We measured the distance 1000 times for angles and ranges on each surface.

Figure 1. Garmin^{TM} LiDAR lite v.3

Table 1 show the key details of LiDAR lite v.3.

Specification	Measurement
Range (70% reflective target)	40 m
Resolution	+/- 1 cm
Accuracy < 5 m	+/- 2.5 cm
Accuracy > 5 m	+/- 10 cm
Wavelength	905 nm
Beam divergence	8 mRad
Total laser power	1.3 W

LiDAR was tested on three important surfaces which consisted of concrete, old asphalt, and uncompressed asphalt. Uncompressed asphalt is the representation of a repaired patch, and it is porous while concrete and old asphalt are dense. As old asphalt has pits and cracks, it is the representation of a damaged surface. Concrete and old asphalt surface is a diffuse-reflective surface, so they reflect energy back to LiDAR very well. The range from LiDAR to the tested surface was 1.0 to 12.0 meters with 15, 30, 45, and 60-degree incident angles.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Elevation Effect Test

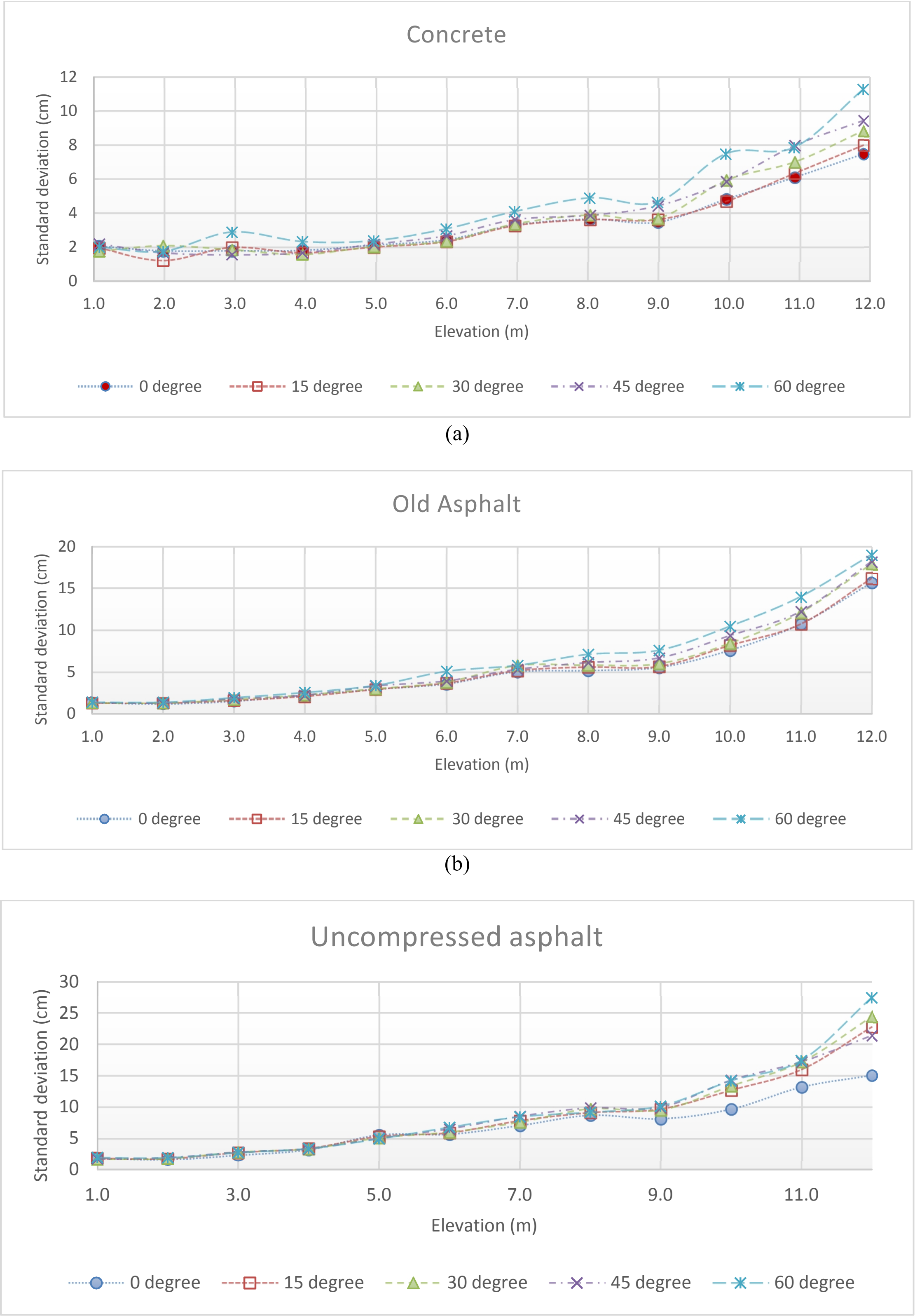
Figure 2 is shown the standard deviation of elevation on each surface. For all kinds of surface, the standard deviation increases quite linearly for 6-meter elevation or lower. However, the standard deviation increases rapidly for the elevation beyond 10 meters. While the standard deviation increases slightly with the incident angle. Hence, the linear, quadratic and exponential regression is studied (Table 2, 3, and 4.). We found that the quadratic and exponential model is closed to the behavior of standard deviation.

3.2 Tilt Angle Effect Test

Tilt angle plays the same role as the incident angle. For large tilt angle and specular surface, the reflected beam tends to reflect out of Lidar view angle. Thanks to the non-specular road surface, measurement error is quite unchanged small and medium tilt angle as seen in Figure 3. The exception is uncompressed asphalt whose porous surface.

3.3 Measurement Failure Test

Because the measurement is not valid in all 1000 times, the percentage of the undetectable reflected beam is the measurement failure in Figure 4. It is seen that measurement failure is very small for overpass elevation. Although this LiDAR technical specification claims that the range on the reflective surface is 40-meter, measurement failure is a catastrophe for 12-13-meter elevation. Thus, it is flawless to use lower than 10-meter elevation on our task.



(a)

(b)

(c)

Figure 2. Standard deviation of elevation measurement of (a) concrete, (b) old asphalt and (c) uncompressed asphalt

Table 2. linear, quadratic and exponential curve fitting between standard deviation and elevation in each incident angle for concrete road surface.

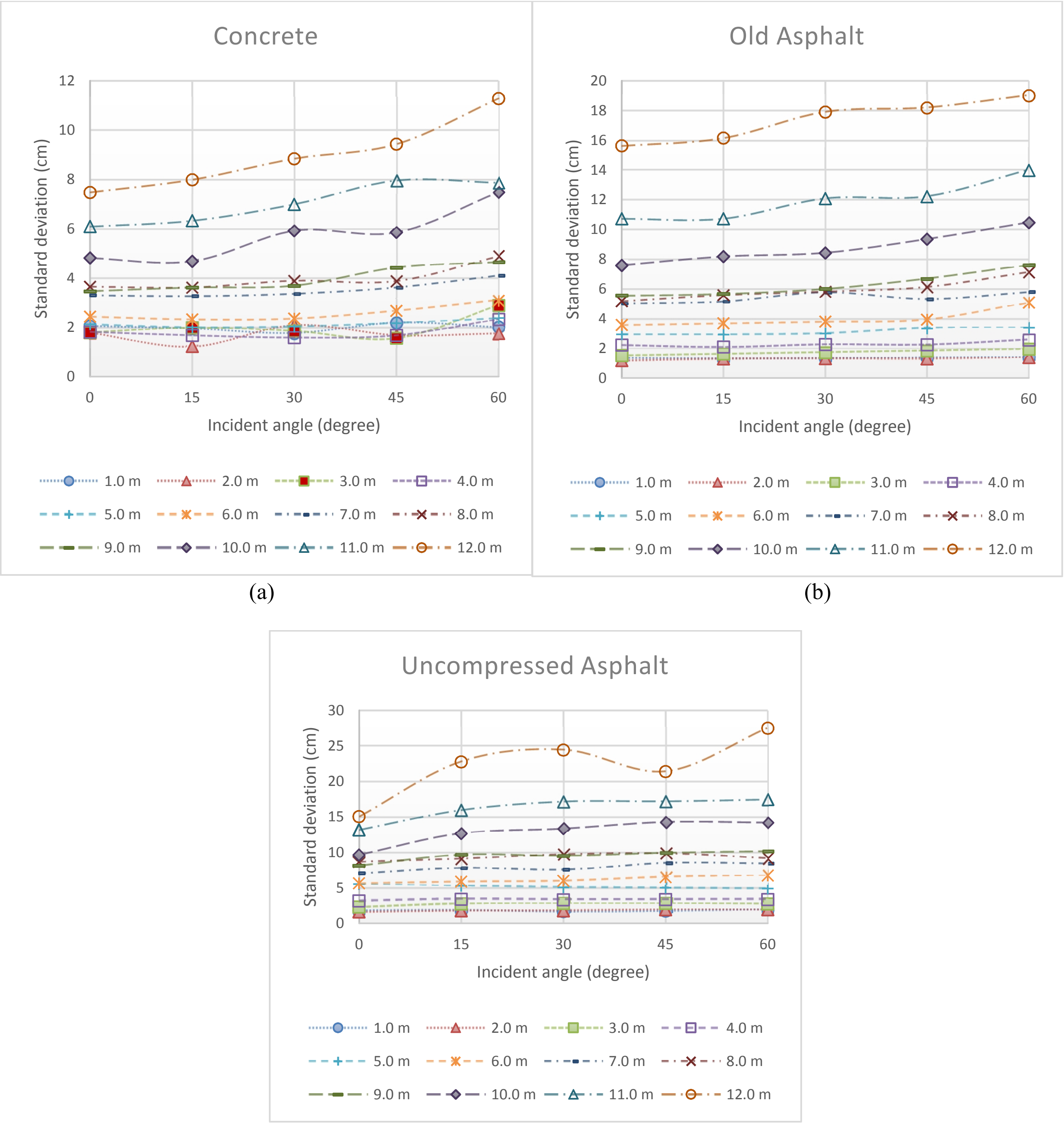
Curve fitting of S.D. vs. elevation for concrete road surface										
Angle (degree)	Linear $y = a + bx$			Quadratic $y = a + bx + cx^2$				Exponential $y = a e^{bx}$		
	a	b	R^2	a	b	c	R^2	a	b	R^2
0	0.362	0.469	0.815	2.459	-0.432	0.070	**0.975**	1.285	0.132	0.896
15	0.046	0.516	0.811	2.323	-0.462	0.076	**0.966**	1.110	0.149	0.891
30	-0.118	0.589	0.800	2.660	-0.604	0.092	**0.975**	1.171	0.152	0.883
45	-0.314	0.655	0.816	2.700	-0.640	0.100	**0.986**	1.140	0.163	0.894
60	-0.210	0.737	0.812	2.914	-0.605	0.104	**0.955**	1.380	0.159	0.919

Table 3. linear, quadratic and exponential curve fitting between standard deviation and elevation in each incident angle for old asphalt road surface.

Curve fitting of S.D. vs. elevation for old asphalt road surface										
Angle (degree)	Linear $y = a + bx$			Quadratic $y = a + bx + cx^2$				Exponential $y = a e^{bx}$		
	a	b	R^2	a	b	c	R^2	a	b	R^2
0	-1.836	1.084	0.815	2.496	-0.773	0.143	0.947	0.888	0.226	**0.974**
15	-1.932	1.123	0.822	2.468	-0.763	0.145	0.950	0.897	0.228	**0.981**
30	-2.278	1.241	0.805	2.797	-0.934	0.167	0.942	0.915	0.234	**0.979**
45	-2.348	1.284	0.827	2.761	-0.906	0.168	0.960	0.941	0.235	**0.985**
60	-2.520	1.410	0.863	2.489	-0.736	0.165	0.974	1.003	0.241	**0.988**

Table 4. linear, quadratic and exponential curve fitting between standard deviation and elevation in each incident angle for uncompressed asphalt road surface.

Curve fitting of S.D. vs. elevation for uncompressed asphalt road surface										
Angle (degree)	Linear $y = a + bx$			Quadratic $y = a + bx + cx^2$				Exponential $y = a e^{bx}$		
	a	b	R^2	a	b	c	R^2	a	b	R^2
0	-0.832	1.177	0.943	1.111	0.344	0.064	**0.969**	1.429	0.205	0.948
15	-2.479	1.650	0.878	2.763	-0.596	0.173	0.968	1.400	0.228	**0.981**
30	-3.029	1.780	0.864	3.027	-0.815	0.200	0.966	1.316	0.239	**0.985**
45	-2.430	1.690	0.922	1.984	-0.202	0.146	**0.986**	1.414	0.232	0.984
60	-3.436	1.921	0.831	3.757	-1.162	0.237	0.950	1.392	0.238	**0.983**



(a)

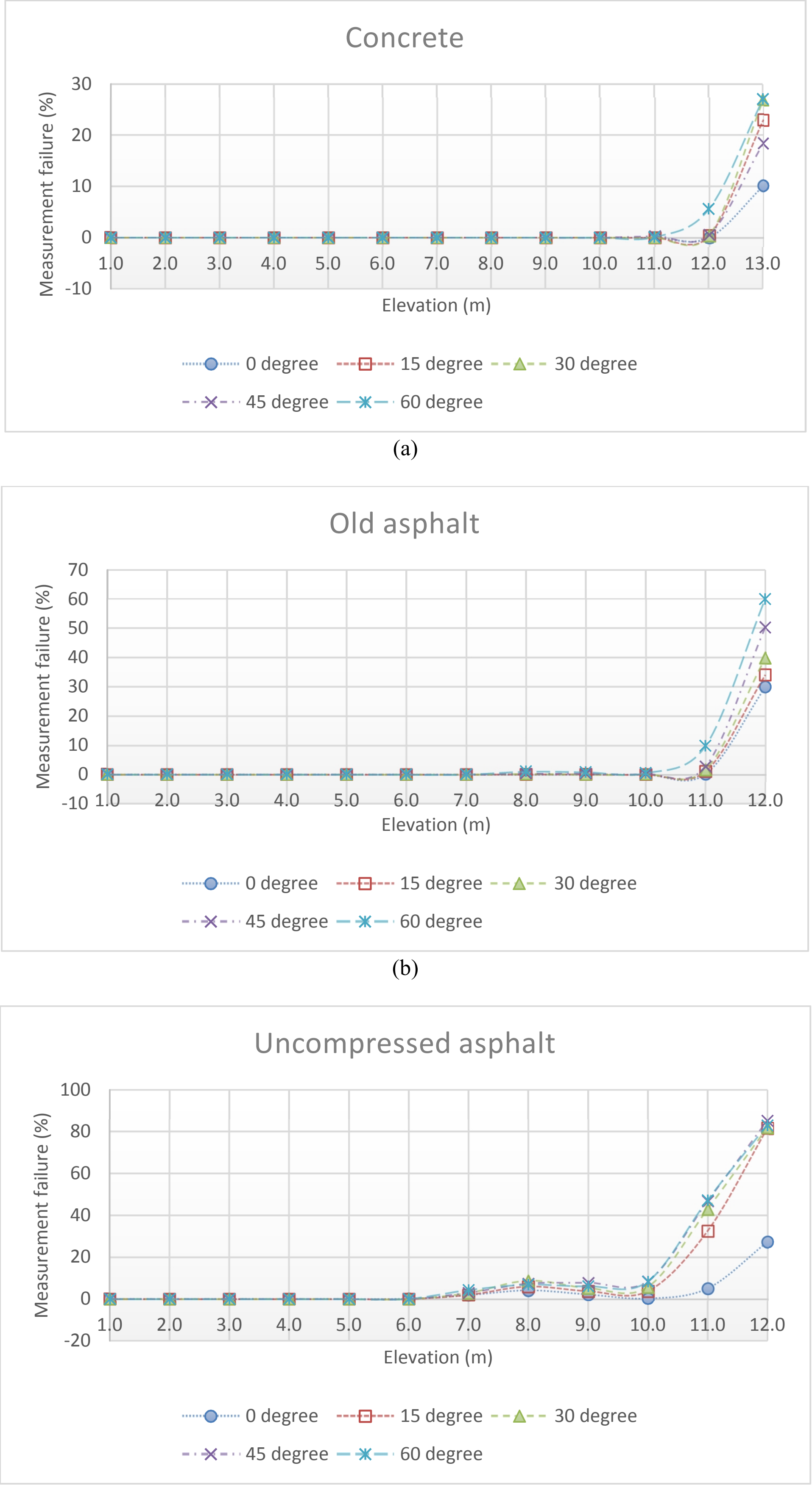
(b)

(c)

Figure 3. Standard deviation of elevation measurement of (a) concrete, (b) old asphalt and (c) uncompressed asphalt with each incident angle.

4. CONCLUSIONS

In this paper, low-cost LiDAR (LiDAR lite v.3) was evaluated in the laboratory for UAV road survey. The results show that measurement failure is small at the range below 6-meter elevation for all incident angles and all three surfaces (concrete, old asphalt, and uncompressed asphalt). This implies that the UAV should fly just above the overpass and use LiDAR to survey the road surface. With this height, this sensor can be done for the surface survey of 10-meter width road.



(a)

(b)

(c)

Figure 4. Percentage of measurement failure in each range of (a) concrete, (b) old asphalt and (c) uncompressed asphalt

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