Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (40) No. (4) October, 2018

Evaluation of Mobile Laser scanners (MLS) and Unmanned Aerial Vehicle (UAV) in Topographic Survey Applications

M. Olwan[a], M. Rabah[b], E. Ghanem[b] and F.Ashraf[a]
[a] Department of Civil Engineering, Higher Technological Institute, Tenth of Ramadan City, Egypt.
[b] Department of Civil Engineering, Benha Faculty of Engineering, Benha University, Egypt.

الملخص العربى :
تعتبر تطبيقات المساحه الطبوغرافيه ضروريه فى مجالات الهندسه المدنيه مثل مشاريع الطرق والمنشاءات وخلافه. فى الوقت الحالى حدث تطور فى الحصول على نماذج ثلاثية الابعاد بسرعه وبدقه عاليه بواسطة موجات الضوء. سيتم من خلال هذه الدراسه تقييم الماسحات الضوئيه المتحركه والطائرات ذاتيه الحركه فى تطبيقات المساحه الطبوغرافيه وذلك عن طريق انشاء نموذج ثلاثى الابعاد واستنتاج قطاعات طوليه وعرضيه وحساب كميات الحفر والردم من بيانات الماسحات الضوئيه المتحركه والطائرات ذاتية الحركه.

ABSTRACT:
Nowadays topographic survey applications are considered as the backbone of most of civil engineering studies, such as road projects, mining enterprises, geological works and building applications. Now the three–dimensional (3D) model is generally achieved by non-contact system based on light waves that can be processed via myriad software packages. With the increasing availability of multiple data sources acquired by different sensor platforms has provided great advantages for desired result achievement.
The current paper evaluates the use of both mobile laser scanning (MLS) data and Unmanned Aerial Vehicle (UAV) images in earth works. Matching data from (MLS) and (UAV) can offer complete and detailed 3D Model.
Point clouds from MLS, UAV were used to build the required road surface that is necessary for drawing the longitudinal profiles and cross sections that are needed to compute the differences between two techniques in elevation along the road. This paper found that the average elevation difference is (0.006044m) in longitudinal profile and (0.15m) in the cross-sections. The current study computed the volume differences resulted from both the cross-sectioning of MLS and UAV, which is (138.89 m^3) for area of (21000m^2). It was concluded that two methods can satisfactorily be used for the computing volume. However, the choice of method should be made according to the location and size of area, required accuracy, budget and time frame.

Kay words: topographic survey, mobile laser scanning (MLS), unmanned aerial vehicle (UAV)

1. INTRODUCTION
As the sensor technology development, multiple data sources acquired by different sensor platforms and different views have provided the great advantages for desired result achievement. The complexity of terrains and scenes, due to its flexible platforms such as aircrafts, cars or vans, trains, boats, trolleys or personal backpacks, can acquire data via mobile sensor technology. Laser scanner based on a an aircraft's platform is called an ALS and has been applied for surveying since 1994, after decades of development, the accuracy and density of point collection has been greatly improved. Ground-based (MLS) might provide complementary measurements for ALS.

MLS can apply different point densities, scanning angles and ranges to the objects compared to ALS. MLS single or multiple can also be used with different platforms, such as car, van or train for urban area data acquisition, boat-mounted MLS equipment for fluvial environments, and backpack versions of MLS used for surveying applications. MLS can be considered to fill the gap between ALS and terrestrial LS (TLS). In MLS, data collection can be performed either in the so-called stop-and-go mode or in a continuous mode. The stop-and-go mode corresponds to conventional TLS measurements; therefore, MLS is hereafter used to refer to the continuous model, i.e., the use of continuous scanning measurements along the drive track. In addition to laser scanners, MLS data acquisition sensors can include accessories, such as digital cameras thermal camera, spectrometers and video cameras. The past few years have seen remarkable development in MLS to accommodate the need for large-area and high resolution 3D data acquisition. MLS serves one of the fastest growing market segments: 3D city modeling.

According to the unmanned vehicle system (UVS) international definition, an unmanned aerial vehicle (UAV) is a generic aircraft design to operate with no human pilot on board. Unmanned aerial vehicle (UAV) platforms are nowadays a valuable source of data for inspection, surveillance mapping, and 3D modeling issues. As UAVs can be considered as a low-cost alternative to the classical manned aerial photogrammetry, new applications in the short and close-range domain are introduced. Rotary or fixed-wing UAVs, capable for performing the photogrammetric data acquisition with amateur camera or digital single lens reflex camera (DSLR), can fly in manual semi-automated, and autonomous modes. A classic photogrammetric workflow, 3D results like digital surface or terrain models, contours, textured 3D models, and vector information can be produced, even on large areas. UAVs are becoming standard platforms for the large-scale mapping of areas of limited extent. The main reasons are the following:

i) survey cost considerations; ii) the safety factor, whereby the lack of a pilot makes it convenient to collect data in disaster areas, e.g., areas affected by floods, earthquakes and tsunamis; iii) low-altitude data acquisition, which fills the gap between high-altitude flight observations and close-range ground-based observations; iv) and their ability to perform data acquisition of locations where MLS cannot observe. Typically, camera-based UAVs collect images with large overlaps. Dense point clouds can be generated from such images.

2. RESERCH METHODOLOGY

2.1 Study area

The test in the current research is located in Al Wafrah, Kuwait. Figure (1) shows the study area in Google maps.

Figure (1): the study area on the Google map.

2.2 Technique properties

2.2.1. TRIMBLE MX2 MOBILE MAPPING SYSTEM

Type	Dual SLM-250 Class 1 lasers
Range	Up to 250 m
Accuracy	±1 cm at 50 m to Kodak white card5
Scanner	FOV 360 degrees
Scan rate	Single laser head: 20 Hz (1200 rpm) Dual laser head: 2 x 20 Hz (1200 rpm)
Maximum effective Measurement rate	Single laser head: 36,000 points per second Dual laser head: 72,000 points per second
Pulse rate	Single laser head: 36 kHz Dual laser head: 2 x 36 kHz

2.2.2. Trimble UX5 HP UNMANNED AIRCRAFT SYSTEM

Resolution (GSD).	1 cm to 25 cm (0.4 in to 9.9 in)
Height above take-off location (AGL).	75 m to 750 m (246 ft to 2,460 ft)
Absolute accuracy (no ground control points).	down to 2 cm (0.8 in)
Relative accuracy (XY/Z).	1-2x/1-5x GSD

Figure (2): Trimble MX2 & Trimble UX5 HP

3. RESULTS AND DISCUSSIONS

3.1 3D surface from MLS and UAV data.

Based upon MLS and UAV point clouds, 3D surface and contour map were created by triangulation with linear interpolation gridding method with spacing (0.217m) in X direction and Y direction and the number of grid line is (76) in X direction and (100) in Y direction. Figure (3) shows the 3D surface obtained from MLS point clouds. Which show that the minimum elevation is (101.56m) and maximum elevation is (101.86m) and the difference between the minimum and maximum elevation is (0.30m).

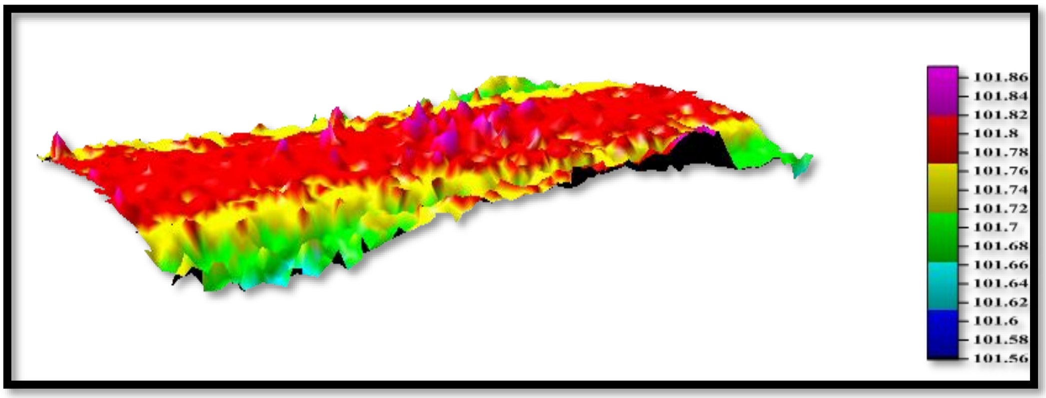

Figure (3):3D Surface from MLS point cloud

Figure (4) shows the contour map obtained from MLS point clouds with interval (0.02m), the minimum elevation is (101.54m), the maximum elevation is (101.88m) and difference between the minimum and the maximum elevation is (0.34m).

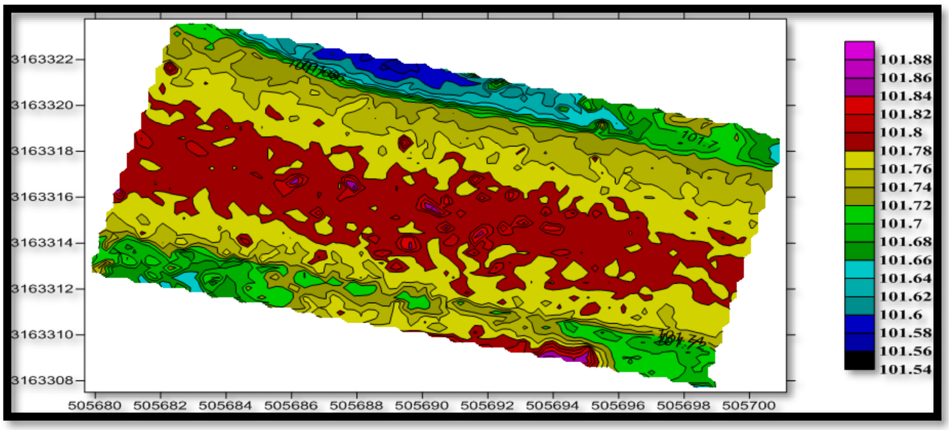

Figure (4): Contour Map from MLS Data

Figure (5) shows the 3D surface obtained from UAV point clouds. It shows that the minimum elevation is (101.35m), maximum elevation is (102.05m) and the difference between the minimum and the maximum elevation is (0.70m).

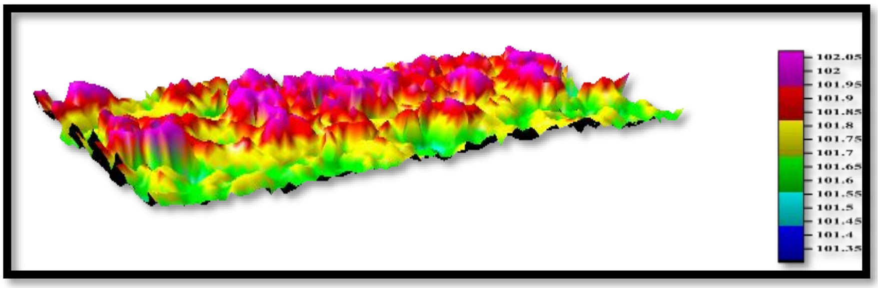

Figure (5): 3D Surface from UAV point cloud

Figure (6) shows the contour map obtained from UAV point clouds with interval (0.05m), the minimum elevation is (101.3m), the maximum elevation is (102.10m) and difference between the minimum and the maximum elevation is (0.80m).

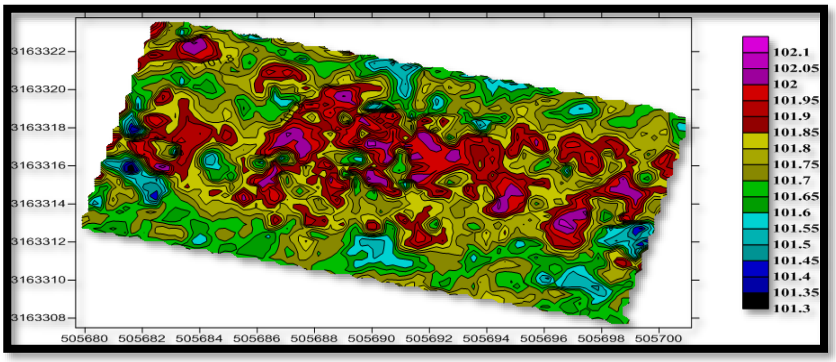

Figure (6): Contour Map from UAV Data

3.2 Study the elevation difference obtained from longitudinal sections.

Three sections along the road with spacing (5m) and length (2170m) with interval (1m) have been generated from 3D surface of MLS and UAV to calculate the average elevation along the road. Figure (7) shows the location of the longitudinal sections of the road.

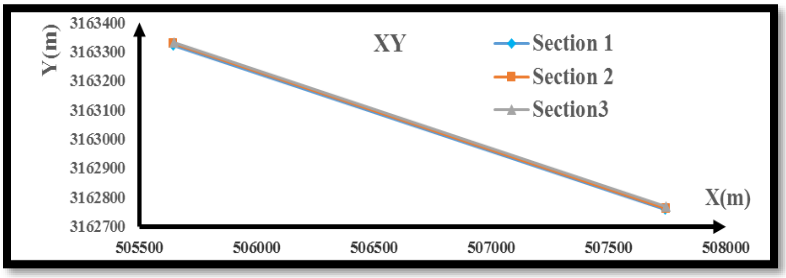

Figure (7): Longitudinal sections location

Table (1) shows the minimum, maximum and average elevation for the three longitudinal sections obtained from 3D surface of MLS and UAV. Which show that the difference between the average elevations of two technique data capture is (0.000126m) for first section, (0.004194m) for second section and (0.013813m) for third section.

Technique	MLS			UAV			Difference	Average difference
Elevation	Z average	Z max	Z min	Z average	Z max	Z min		
Section 1	101.1453	102.879	98.606	101.1451	102.95	98.613	0.000126	
Section 2	101.3185	102.996	98.852	101.3227	102.985	98.724	0.004194	0.006044
Section 3	101.1992	102.944	98.78	101.213	102.965	98.751	0.013813	

Table (1): Elevations obtained from MLS and UAV longitudinal sections.

The station and elevation for the three longitudinal sections obtained from 3D surface of MLS and UAV show in figures (8, 9, 10, 11, 12, and 13). The tables (2, 3, 4, 5, 6, and 7) show the coordinate of the sections and the maximum, minimum, and average elevation.

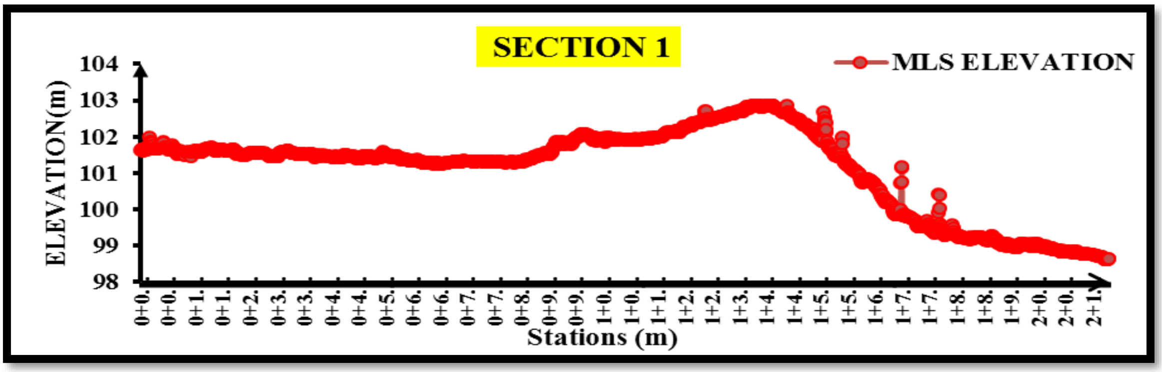

Figure (8): Station and elevation (MLS).

SECTION 1	SECTION LOCATION			Z average	Z max	Z min
	X	Y	Z			
Start	505645.868	3163321.911	101.618	101.1452734	102.879	98.606
End	507742.344	3162757.575	98.641			

Table (2): Section (1) MLS.

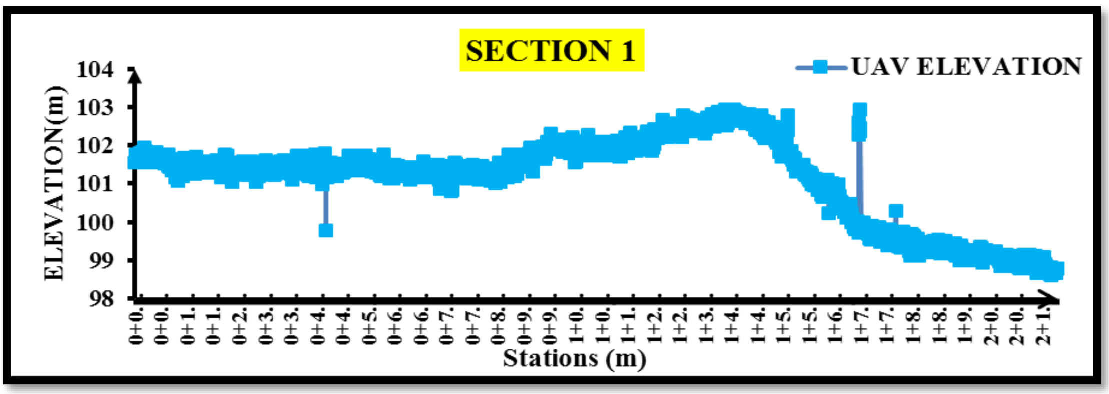

Figure (9): Station and elevation (UAV).

SECTION 1	SECTION LOCATION			Z average	Z max	Z min
	X	Y	Z			
Start	505645.868	3163321.911	101.547	101.1451477	102.95	98.613
End	507742.344	3162757.575	98.799			

Table (3): Section (1) UAV.

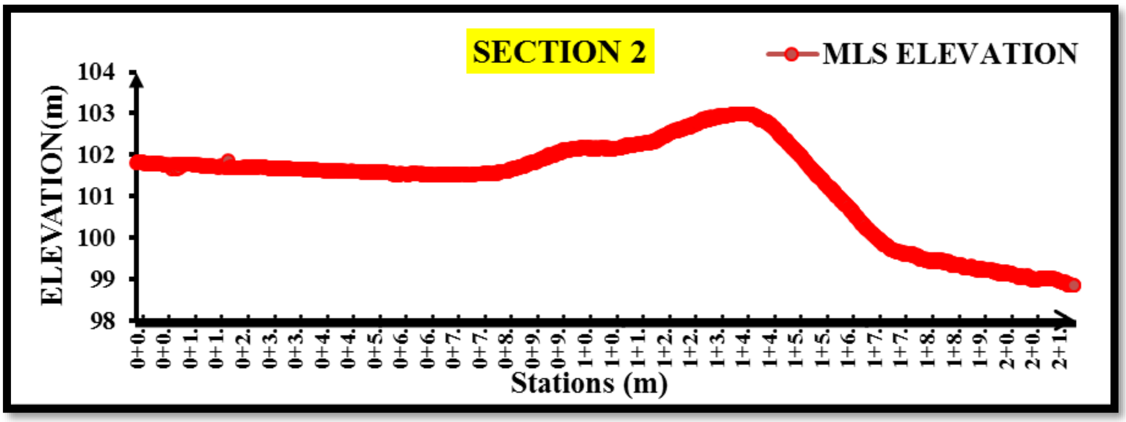

Figure (10): Station and elevation (MLS).

SECTION 2	SECTION LOCATION			Z average	Z max	Z min
	X	Y	Z			
Start	505646.9118	3163326.808	101.795	101.3185449	102.996	98.852
End	507743.3878	3162762.472	98.853			

Table (4): Section (2) MLS.

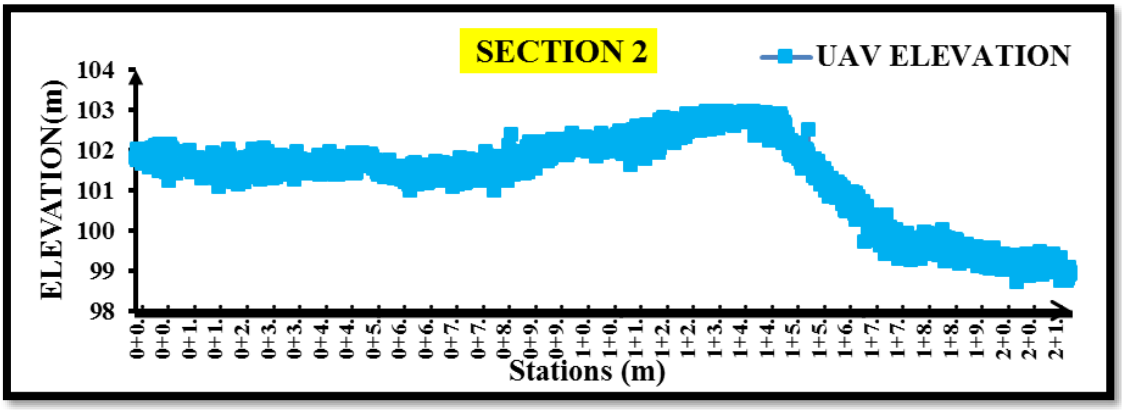

Figure (11): Station and elevation (UAV).

SECTION 2	SECTION LOCATION			Z average	Z max	Z min
	X	Y	Z			
Start	505646.9118	3163326.808	101.83	101.3227391	102.985	98.724
End	507743.3878	3162762.472	98.969			

Table (5): Section (2) UAV.

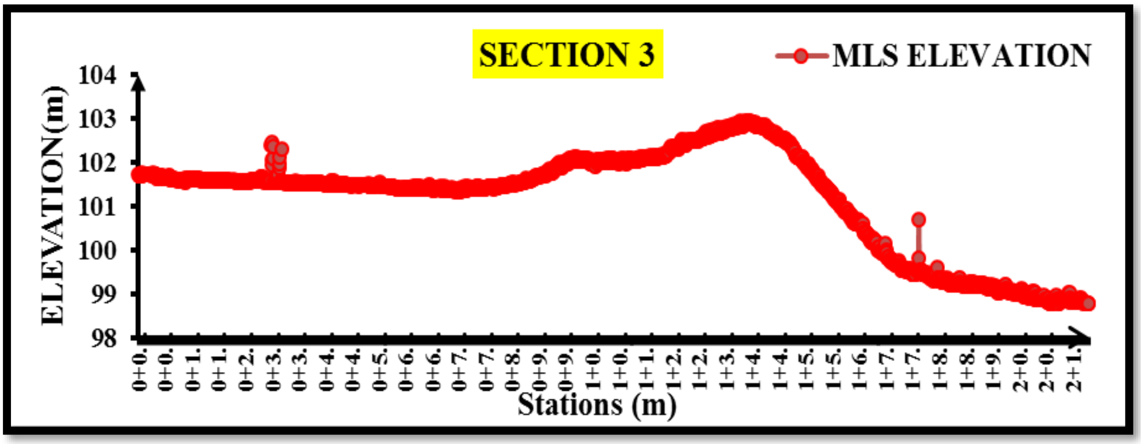

Figure (12): Station and elevation (MLS).

SECTION 3	SECTION LOCATION			Z average	Z max	Z min
	X	Y	Z			
Start	505647.9535	3163331.706	101.721	101.1991753	102.944	98.78
End	507744.3588	3162767.389	98.797			

Table (6): Section (3) MLS.

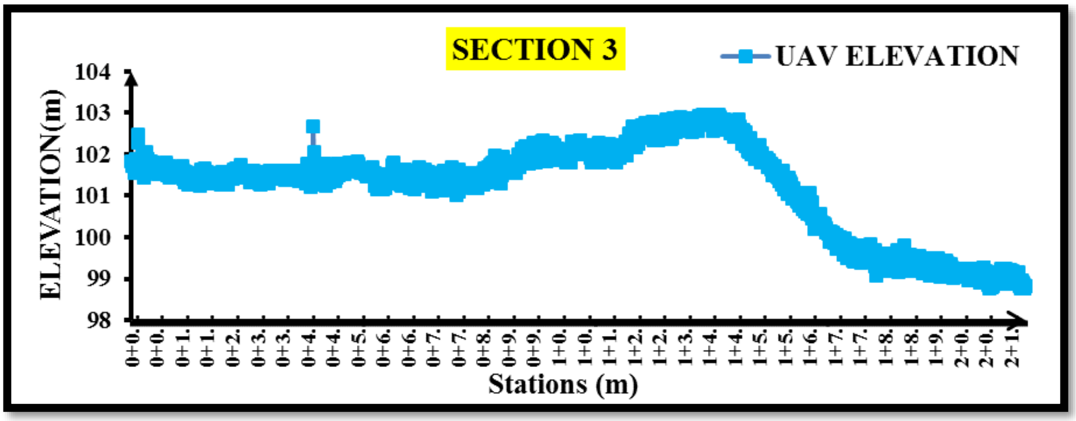

Figure (13): Station and elevation (UAV).

SECTION 3	SECTION LOCATION			Z average	Z max	Z min
	X	Y	Z			
Start	505647.9535	3163331.706	101.828	101.2129885	102.965	98.751
End	507744.3588	3162767.389	98.816			

Table (7): Section (3) UAV.

3.3 Study the elevation differences of the cross sections.

Tenth cross sections along the road with spacing (250m) and width (10m) with interval (1m) have been generated from 3D surface of MLS and UAV to calculate the average elevations of the cross sections. Figure (14) shows the location of the cross sections along the road.

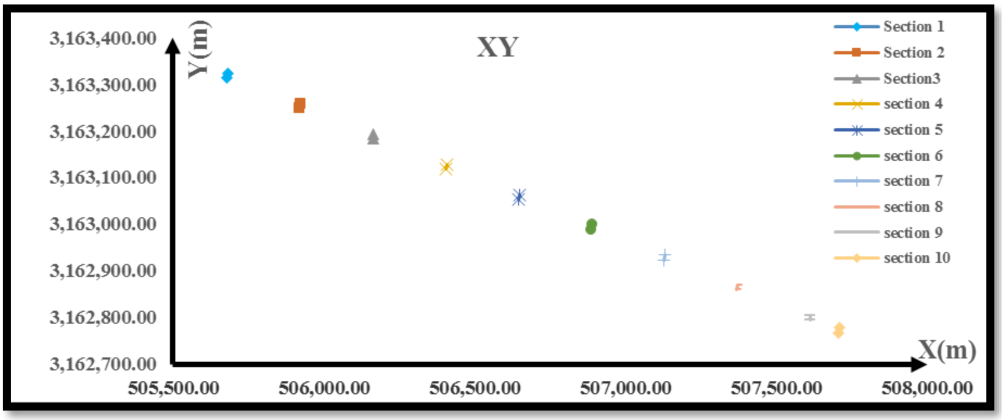

Figure (14): Cross sections locations.

Table (8) shows the minimum, maximum and average elevation along the tenth cross sections obtained from 3D surface of MLS and UAV. Which show that the average elevation from MLS cross sections is (100.51m) and of UAV cross sections is (100.66m).

sections		Section1	Section2	Section3	Section4	Section5	Section6	Section7	Section8	Section9	Section10	Average	Difference
MLS	**Average Elevation**	101.76	101.60	101.35	101.07	100.96	100.65	100.18	99.54	99.08	98.90	100.51	0.15
UAV	**Average Elevation**	101.85	101.47	101.49	101.14	101.17	100.99	100.52	99.66	99.23	99.04	100.66	

Table (8): Elevation from MLS and UAV cross sections.

The distance and elevation of the tenth cross sections obtained from 3D surface of MLS and UAV show in figure (15, 16, 17, 18, 19, 20, 21, 22, 23 and 24). The tables (9, 10, 11, 12, 13, 14, 15, 16, 17, and 18) show the coordinate of the section and the average elevation.

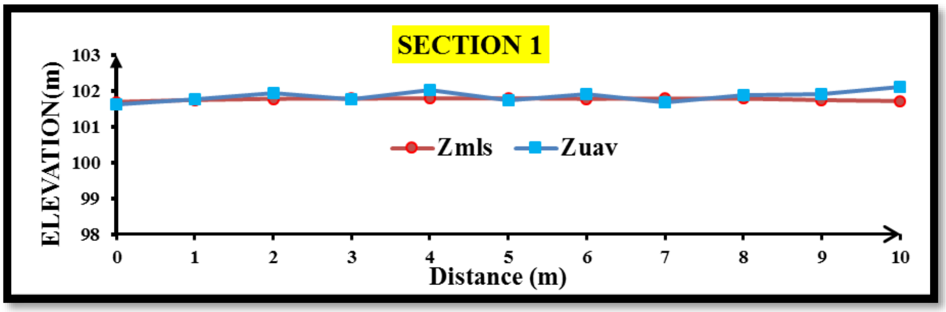

Figure (15): Distance and elevation.

SECTION 1	SECTION LOCATION					
	X	Y	Z		Z average	
			MLS	UAV	MLS	UAV
Start	505,679.57	3,163,313.81	101.689	101.615	101.76	101.85
End	505,682.17	3,163,323.47	101.715	102.117		

Table (9): Section (1) MLS and UAV.

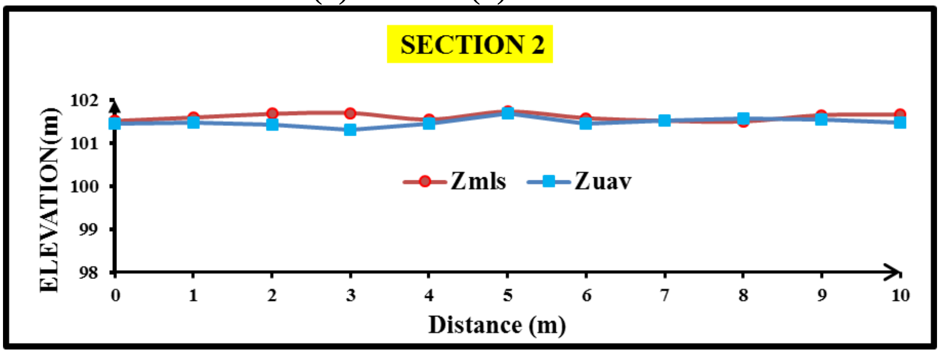

Figure (16): Distance and elevation.

SECTION 2	SECTION LOCATION					
	X	Y	Z		Z average	
			MLS	UAV	MLS	UAV
Start	505,920.97	3,163,248.79	101.504	101.433	101.60	101.47
End	505,923.57	3,163,258.44	101.653	101.474		

Table (10): Section (2) MLS and UAV.

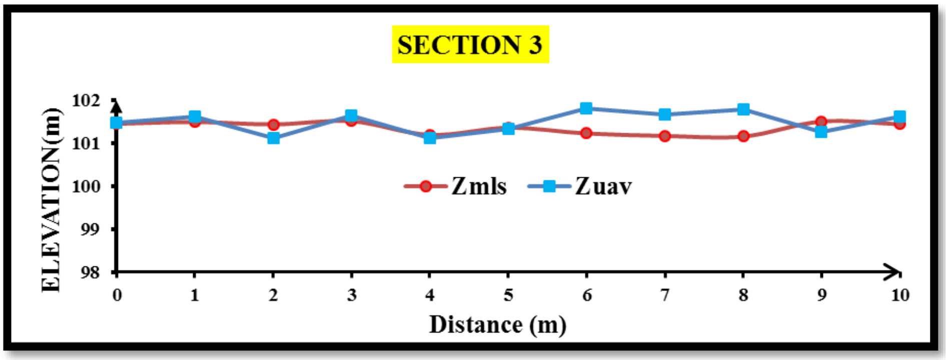

Figure (17): Distance and elevation.

<table>
<tr><td rowspan="3">SECTION 3</td><td colspan="6">SECTION LOCATION</td></tr>
<tr><td rowspan="2">X</td><td rowspan="2">Y</td><td colspan="2">Z</td><td colspan="2">Z average</td></tr>
<tr><td>MLS</td><td>UAV</td><td>MLS</td><td>UAV</td></tr>
<tr><td>Start</td><td>506,162.36</td><td>3,163,183.76</td><td>101.441</td><td>101.471</td><td rowspan="2">101.35</td><td rowspan="2">101.49</td></tr>
<tr><td>End</td><td>506,164.96</td><td>3,163,193.41</td><td>101.431</td><td>101.613</td></tr>
</table>

Table (11): Section (3) MLS and UAV.

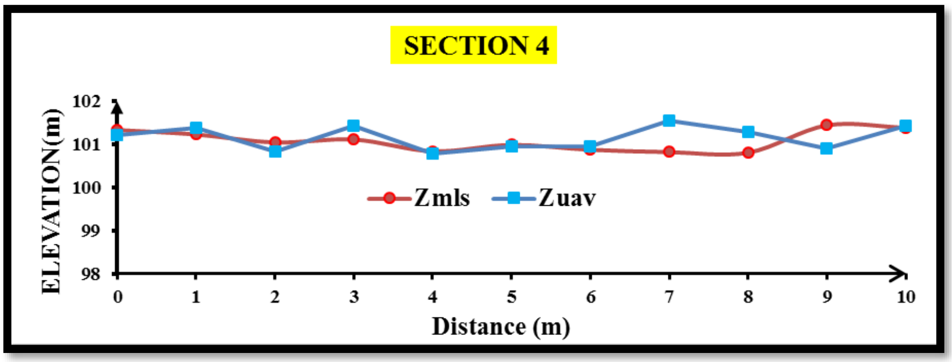

Figure (18): Distance and elevation.

<table>
<tr><td rowspan="3">SECTION 4</td><td colspan="6">SECTION LOCATION</td></tr>
<tr><td rowspan="2">X</td><td rowspan="2">Y</td><td colspan="2">Z</td><td colspan="2">Z average</td></tr>
<tr><td>MLS</td><td>UAV</td><td>MLS</td><td>UAV</td></tr>
<tr><td>Start</td><td>506,403.76</td><td>3,163,118.73</td><td>101.322</td><td>101.197</td><td rowspan="2">101.07</td><td rowspan="2">101.14</td></tr>
<tr><td>End</td><td>506,406.36</td><td>3,163,128.39</td><td>101.373</td><td>101.423</td></tr>
</table>

Table (12): Section (4) MLS and UAV.

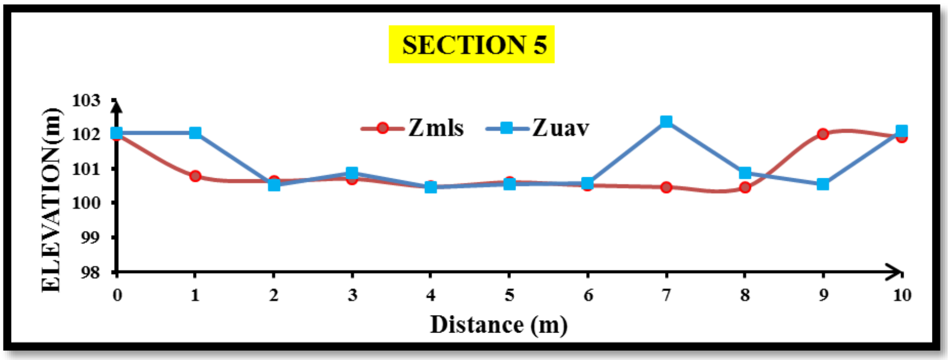

Figure (19): Distance and elevation.

<table>
<tr><td rowspan="3">SECTION 5</td><td colspan="6">SECTION LOCATION</td></tr>
<tr><td rowspan="2">X</td><td rowspan="2">Y</td><td colspan="2">Z</td><td colspan="2">Z average</td></tr>
<tr><td>MLS</td><td>UAV</td><td>MLS</td><td>UAV</td></tr>
<tr><td>Start</td><td>506,645.15</td><td>3,163,053.71</td><td>101.988</td><td>102.043</td><td rowspan="2">100.96</td><td rowspan="2">101.17</td></tr>
<tr><td>End</td><td>506,647.75</td><td>3,163,063.36</td><td>101.925</td><td>102.082</td></tr>
</table>

Table (13): Section (5) MLS and UAV.

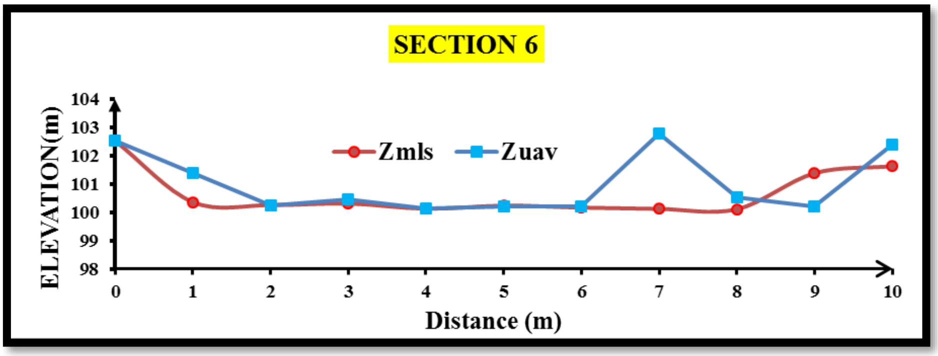

Figure (20): Distance and elevation.

SECTION 6	SECTION LOCATION					
	X	Y	Z		Z average	
			MLS	UAV	MLS	UAV
Start	506,886.55	3,162,988.68	102.513	102.51	100.65	100.99
End	506,889.15	3,162,998.33	101.619	102.362		

Table (14): Section (6) MLS and UAV.

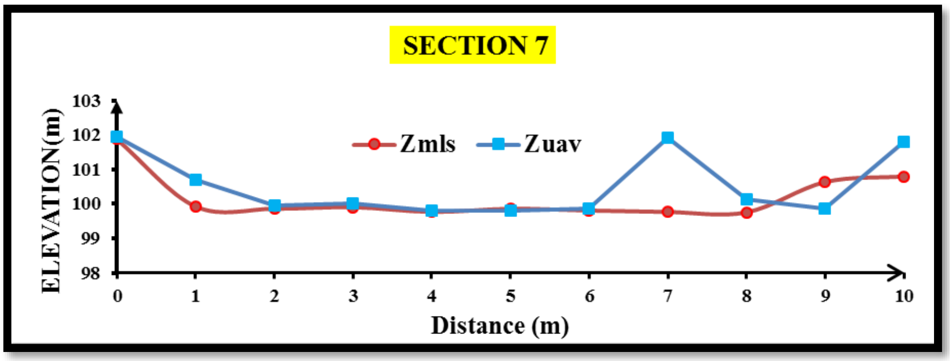

Figure (21): Distance and elevation.

SECTION 7	SECTION LOCATION					
	X	Y	Z		Z average	
			MLS	UAV	MLS	UAV
Start	507,127.94	3,162,923.65	101.87	101.941	100.18	100.52
End	507,130.54	3,162,933.31	100.797	101.782		

Table (15): Section (7) MLS and UAV.

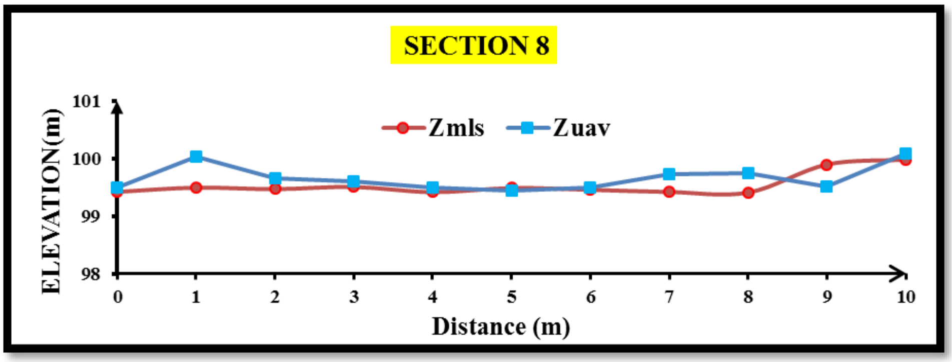

Figure (22): Distance and elevation.

SECTION 8	SECTION LOCATION					
	X	Y	Z		Z average	
			MLS	UAV	MLS	UAV
Start	507,369.34	3,162,858.63	99.417	99.486	99.54	99.66
End	507,371.94	3,162,868.28	99.976	100.082		

Table (16): Section (8) MLS and UAV.

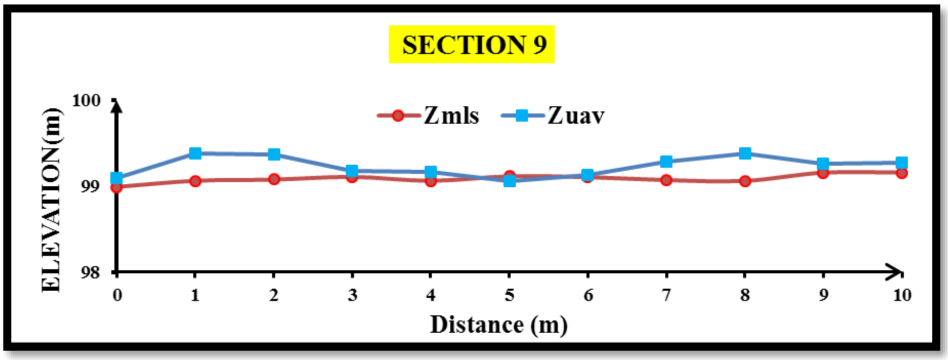

Figure (23): Distance and elevation.

SECTION 9	SECTION LOCATION					
	X	Y	Z		Z average	
			MLS	UAV	MLS	UAV
Start	507,610.73	3,162,793.60	98.988	99.093	99.08	99.23
End	507,613.33	3,162,803.26	99.155	99.265		

Table (17): Section (9) MLS and UAV.

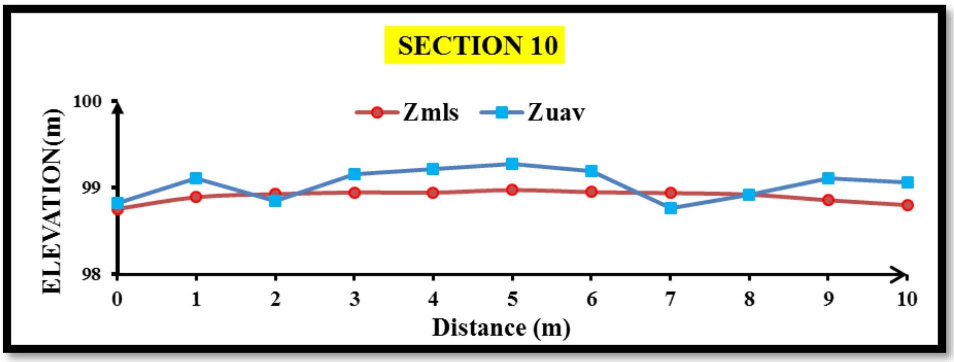

Figure (24): Distance and elevation.

SECTION 10	SECTION LOCATION					
	X	Y	Z		Z average	
			MLS	UAV	MLS	UAV
Start	507707.28	3162767.59	98.754	98.826	98.90	99.04
End	507,709.88	3,162,777.25	98.798	99.06		

Table (18): Section (10) MLS and UAV.

3.4 Study the volume computing obtained from MLS and UAV data.

Generally, in land engineering projects (roads, construction, mining, etc.) it is necessary to compute land volumes for excavation and filling in order to determine the cost of the work. Several methods can be used to compute the volume with each method having its advantages and disadvantages depending on the shape of the object. The objects can be divided into two categories: linear and surface. Streets, railways, dams and tunnels are types of linear objects; landfills, shaft pits and dumps are examples of surface objects. For linear objects the commonly used method is cross-sectioning. The volume of a surface object can be computed with the trapezoidal method (rectangular or triangular prisms), classical cross-sectioning (trapezoidal, Simpson and average formula) and improved methods (Simpson-based, cubic spline and cubic Hermite formula).in this study the cut volumes from cross sections along the road with interval (10m) and width (10m) of total length of the road (2100m) have been computed. The number of sections are 210 sections obtained from 3D surface of MLS and UAV. According the computed volumes, an evaluation can be performed to indicate for what extent the accuracy of the two techniques can be used in topographic surveying applications. Table (19) shows example for sections coordinate, cut area and cut volumes from 3D surface of MLS and UAV. The volume values calculated by civil 3D program.

Station	Easting	Northing	MLS Elevation Existing	UAV Elevation Existing	Cut Area (m^2)		Cut volume (m^3)	
					MLS	UAV	MLS	UAV
0+250.00	505920.9654	3163248.785	101.504	101.433	36.66	34.88	366.28	351.48
0+500.00	506162.3604	3163183.759	101.441	101.471	35.29	37.32	353.45	374.85
0+750.00	506403.7554	3163118.732	101.322	101.197	34.82	34.62	347.89	341.32
1+000.00	506645.1504	3163053.706	101.988	102.043	41.1	41.4	411.15	415.72
1+250.00	506886.5454	3162988.679	102.513	102.51	46.52	46.72	463.84	455.74
1+500.00	507127.9404	3162923.653	101.87	101.941	39.66	39.85	401.56	404.36
1+750.00	507369.3354	3162858.626	99.417	99.486	15.64	16.4	156.76	163.31
2+000.00	507610.7304	3162793.599	98.988	99.093	10.57	11.64	107.25	120.78
2+100.00	507707.2881	3162767.589	98.754	98.826	9.14	10.62	93.9	108.68

Table (19): Example from sections volume values.

Figure (25) shows the Stations and volumes value for cross section along the road. The minimum difference between volumes is ($0.01m^3$), the maximum difference is ($24.63m^3$) and the average difference between volumes is ($8.614429m^3$).

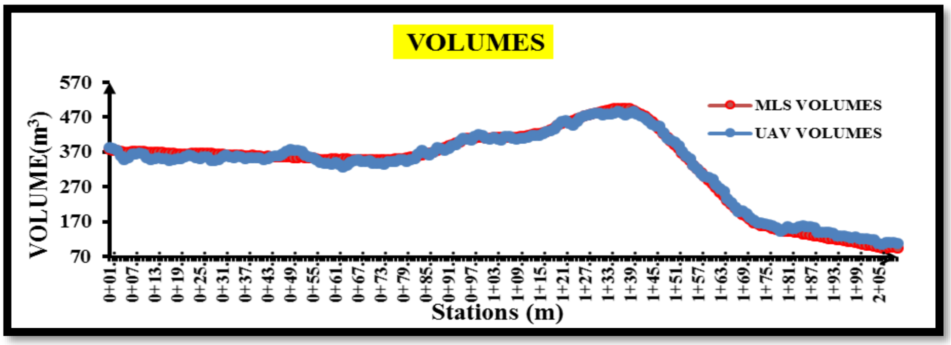

Figure (25): Stations and volumes value.

As it is demonstrated in table (20), the total cut volume of MLS cross sections is ($69510.66m^3$) for number of cross sections (210) and area ($21000m^2$). The number of

MLS point clouds is (265440). The total cut volume for UAV cross sections is (69371.77m³) for the same number of cross sections and related area. The number of UAV point clouds is (259671). The total difference in volume value between two techniques of this study is (138.89m³), which represents % 0.002 of the computed volumes. The resulted percentage confirms that both techniques are compliant with each other for a high degree.

Technique	CUM-VOLUMES(m^3)	AREA(m^2)	RATIO(m^3/m^2)	NO OF POINTS
MLS	69,510.66	21000	0.00661381	265440
UAV	69,371.77	21000		259671

Table (20): volume report.

4. Conclusions.

The current study has demonstrated that the two techniques MLS and UAV can satisfactorily be used for topographic surveying applications such as volume computing however, the choice of method should be made according to the location and size of area, budget and time frame.

REFERENCES

Cramer, M., Stallmann, D. and Haala, N., 2000. Direct Geo-Referencing Using GPS/Inertial Exterior Orientations for Photogrammetric Applications. International Archives of Photogrammetry and Remote Sensing, Amsterdam, The Netherlands. Vol. 33, Part B3, pp. 198-205**.**

Zhu, L., Jaakkola, A., Hyyppä, J., 2013. The use of Mobile Laser Scanning data and Unmanned Aerial Vehicle images for 3D model reconstruction. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-1/W2, 2013, UAV-g2013, 4 – 6 September 2013, Rostock, Germany.

Yanalak M. Computing pit excavation volume. *Journal of Surveying Engineering* **131**(1) (2005), 15–19.

Kadobayashi R., Kochi N., Otani H. and Furukawa R. Comparison and evaluation of laser scanning and photogrammetry and their combined use for digital recording of cultural heritage. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences **35**(5) (2004), 401–406.

Kukko, A.; Kaartinen, H.; Hyyppa, J.; Chen, Y. Multiplatform mobile laser scanning: Usability and performance. Sensors **2012**, 12, 11712–11733.

Pu, S.; Rutzinger, M.; Vosselman, G.; Elberink, S.O. Recognizing basic structures from mobile laser scanning data for road inventory studies. *ISPRS J. Photogramm. Remote Sens*. **2011**, *66*, 28–39.

Clode, S.; Rottensteiner, F.; Kootsookos, P.; Zelniker, E. Detection and vectorisation of roads from LIDAR data. *Photogramm. Eng. Remote Sens*. **2007**, *73*, 517–535.

Kukko, A. Road Environment Mapper—3D Data Capturing with Mobile Mapping. Licentiate's Thesis, Helsinki University of Technology, Espoo, Finland, 2009; p. 158.