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RESEARCH ARTICLE

Cost-Efficient Digital Elevation Model (DEM) Acquisition on Flume Tank Morphodynamic Observation

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Abstract

Digital Elevation Model (DEM) is well known for providing solutions to the theoretical and application-related problems around geosciences. The use of DEM in flume tank experiment is getting more common nowadays. Flume tank itself is built to simulate the landscape and stratigraphy at laboratory scale. This physical experiment may have tremendous impacts on understanding the sedimentation process in a laboratory-scaled experiment. Normally, the morphodynamic behaviour of a laboratory-scaled deposit in the flume tank experiment would be observed through its digital elevation model. In this paper, a novel method in constructing cost-efficient digital elevation model was presented. By using this inexpensive tool to create a digital elevation model in a flume tank experiment setup, some challenges and benefits will follow this method. Some challenges including tool's resolution and time consuming could be diminished in the near future by creating automated motor system to move the laser distance meter sequentially. Automated and integrated system from the LDM to the processing software could also reduce the time consumption. In the other hand, some benefits including financial benefit, reliability in a sedimentary structure scale, and also the practicality to be applied in any flume tank system available in Indonesia. Nevertheless, this method had been tested and some reliable results from the previous studies in Quantitative Sedimentology Laboratory, Universitas Indonesia was presented in this paper. Hopefully, some major improvements could be done to get more accurate and detail digital elevation model in the near future.

Keywords: flume tank, digital elevation model, laser distance meter, quantitative sedimentology

1. Introduction

A Digital Elevation Model (DEM) is an array representation of squared cells (pixels) with an elevation value associated with each pixel (Rishikeshan et al., 2014). DEM represents three-dimensional information of terrain and provide basic information required to characterize the topographic attributes (Hutchinson and Gallant, 2000).

DEM is well known for providing solutions to the theoretical and application-related problems around geosciences. For example, DEM has very important role in hydrological modelling (Hopkinson et al., 2009, Le Coz et al., 2009, Li et al., 2017), geological studies (Yang et al., 2011), disaster analysis (Tsai et al., 2010), agricultural field and applications, and so on. From previous studies above, the general workflow for land surface DEM-based morphodynamic analysis requires initial detailed identification and delineation of surface-specific elements, such as peaks, ridge lines, course lines. Though usually this is often done through human-made analysis from one or more DEM-derived surface parameters that fits (Favalli, 2012).

Hence, DEM generation with various data sources have been attracting attention in the research community (Shen et al., 2016). Many are using contours as data source as it is very inexpensive data source (Li et al., 2017). In fact a contour is an iso-line which represents a series of points of equal elevation. Contours also have inherent property of consecutive equivalence and topographical property, which a justifiable reason to use contours as data source for DEM generation. DEM generation from contours can be divided into two types : point methods and line methods (Oky et al., 2002). The point methods utilizing discrete vertices along the contours to obtain elevation value along the grids, based on point characteristics. On the other hand, line methods use all the points along contours and make use of the line characteristics. The result provided are generally satisfactory.

Nowadays, using flume tank experiment as a quantitative physical model of sedimentation mechanism is more common. Recent years have seen a bloom of experiments designed to reproduce aspects of the dynamics of natural landscapes at greatly reduced scale (Paola et al., 2009). Flume tank that is commonly used by geologist has been utilized to simulate or to experiment landscape and stratigraphy at laboratory scale (Reynolds, 1887). Experiments have two advantages over real-world data, namely full control over the initial and boundary conditions, and rapid evolution that can be witnessed and recorded (Kleinhans et al., 2014).

In Universitas Indonesia, we have used this experiment facility to conduct several studies such as the origin of some sedimentary structures namely wave, ripple, and cross-lamination from natural world measurement (i.e. northern coast of Jakarta, Cisadane River, etc.) (Fig 1). This 3m x 1m flume tank is highly effective in understanding both the process and the product of sedimentation. The main advantage of using this facility is that we could observe clearly the evolution of sedimentary structure and process in a laboratory scale. The physics behind the experiment consisted of spatial and process scaling-down from the real-world phenomenon remains reliable during the experiment.

In order to record the experiment, we have used several cameras, flowmeter on inlet and outlet, particle image velocimetry (PIV) to record the flow velocity on the tank, and also a laser distance meter to construct a DEM. We have constructed inexpensive, cost-efficient DEM acquisition for quantitative morphodynamic observation. The performance of this DEM acquisition will be adequate enough for represent morphodynamic properties to some extends.

In the other hand, using laser distance meter to create a DEM will be beneficial for the student in order to observe and to compare between the real-world phenomenon and laboratory-scaled experiment. During the process of understanding the construction of cross lamination or ripple structure for example, the student could now observe the real-world occurrence such as in river bed and coastal plain with the comparison in a laboratory-scaled sedimentary structures that preserve the physics behaviour behind it. The comparison between the real-world observation and DEM built in this study would also presented at the end of this paper.

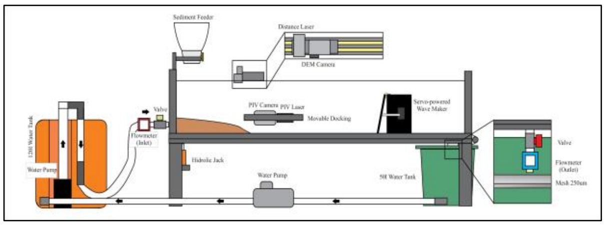

Fig 1. Schematic diagram of flume tank facility used in Universitas Indonesia

2. DEM Construction

For the acquisition we assembled several materials and constructed all parts into fully working DEM instrument. For the chassis, we use two iron pipes of half-inch diameter size with 130 cm long which in our case is for covering the width of our flume tank.

The movable part made from assembling three-quarter inch size of PVC pipes which two has 39 cm long and other two has 19 cm long. Each end of the pipes jointed and arranged with T-shaped pipe socket of three-quarter inch size (Fig. 2). Inside the movable base, we put up a plank of wood as base surface for putting the laser distance meter (LDM).

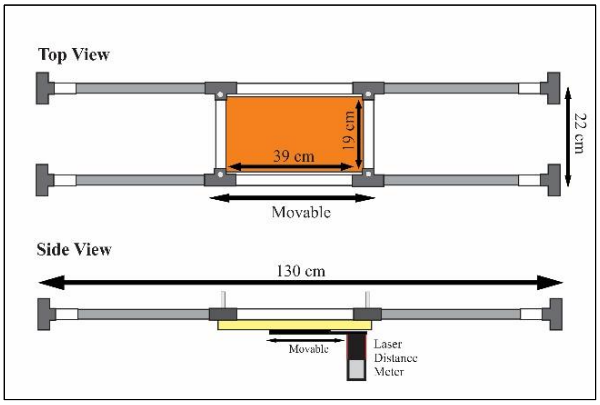

Fig 2. Schematic diagram of laser distance meter that is set on top of a flume tank facility

The Laser Distance Meter instrument is fixed on a modified double-barrel rail which usually used as drawer rail. The rail is modified so it can be moved back and forth for covering a greater distance and flexibility in moving the LDM.

We used iron pipe that has quarter inch size smaller than the PVC pipe on movable apparatus because the size differs so the movable part is able to slide along the iron pipe without huge friction or getting stuck. This pipe was then scaled every millimetre in order to get their own coordinate system that will be explained later on.

At the end of each iron pipe, we put another T-shaped pipe socket for making the instrument able to hang on the each side of flume tank along the width.

Every time it is used, this tool will follow a simple procedure of data acquisition, data processing, and data presentation (Fig. 3)

3. DEM Construction Workflow

Conceptually, DEM is built by using several data points on a set coordinate system. In a flume tank system, its laboratory size (3m x 1m) made the construction of its own coordinate system is compulsory. The way the scale was created was by making millimetre marks on the railing where the LDM is attached. This marks will then be used as its Y axis. The X axis of this system will benefit the flume tank glass boundary by creating other millimetre marks on each side of the flume tank wall. This X and Y axis will now be the coordinate system of this DEM-creator. The more detail scale system built and the more smooth movement of the LDM following the scale, the higher the DEM resolution will be.

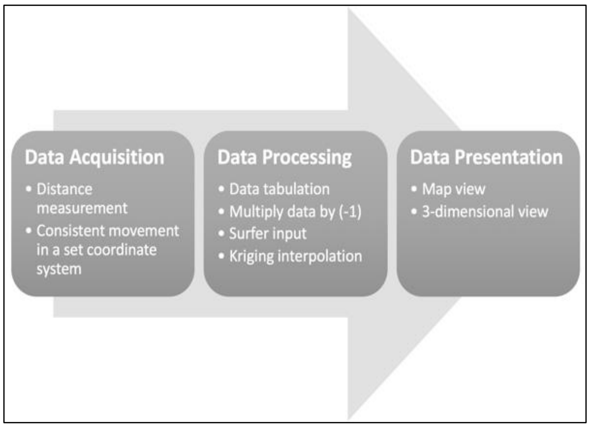

Fig 3. General procedure of data acquisition to data presentation of a DEM in a flume tank facility

Every time the LDM acquire the data by clicking the button in this tool, a distance value will show on the screen. This single value is the distance measured by the laser that will be set in the coordinate system of X, Y, and Z (Table 1). The tool originally could save up to 50 measurement points, this will benefit the user to save more time in during the data acquisition.

Table 1. An example of data acquisition of 3mm x 5mm area (coordinate system) in a flume tank experiment with Z axis comprising the distance acquired by the laser distance meter.

X (mm)	Y (mm)	Z (m)
0	1	0.5
0	2	0.51
0	3	0.56
0	4	0.34
0	5	0.55
1	1	0.12
1	2	0.65
1	3	0.54
1	4	0.55
1	5	0.56
2	1	0.57
2	2	0.59
2	3	0.56
2	4	0.91
2	5	0.32
3	1	0.44
3	2	0.51
3	3	0.51
3	4	0.66
3	5	0.3

During the data processing step, all the data should be tabulated in any computational software. This processing step will comprise of multiply the Z data by minus 1 to acquire the positive contour correctly. This step is compulsory because the acquisition process was done on top of the flume tank. This calculation is not always needed if the acquisition process is from another different angle. Afterward this tabulated data will be an input data for Surfer® by Golden Software.

This scattered X,Y, and Z data will need to be interpolated in order to create the surface in that software. Kriging interpolation was used where this geostatistical method will generate an estimated surface from a scattered set of points with z-values. This method is also called Gaussian process regression in some other software. The surface made by this method was then presented as the digital elevation model of the observed laboratory-scaled landscape.

Normally, during the data presentation, some colours highlighting the contours difference will be used. The use of this colours will benefit in differentiating the high and low of the contours. Map view and 3D view of this DEM is possible to be presented during this process (Fig. 4).

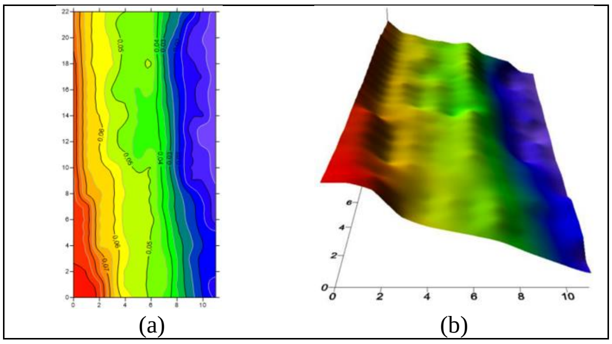

Fig 4. An example of the result from Kriging interpolation from Surfer® software (a) map view representation of a gentle slope (b) 3D view of the same laboratory-scaled morphological feature.

4. Results

Results from the previous studies are represented in this paper in order to see the reliability of this method. Some studies on coastal plain deposit, wave ripple sedimentary structures, and atoll-like siliciclastic deposit using this method were presented in the following figures.

Figure 5a represented the coastal plain laboratory-scaled deposit. This deposit was then measured using the LDM in order to build the respective DEM (Fig. 5b,5c). From this previous study, two distinct black mica lines deposited across the coastal plain could be seen clearly on the digital elevation model of cm-resolution scale. Better resolution could be acquired by creating millimetre scale system both in X and Y axis.

On the study of atoll-like siliciclastic deposit, this method could moderately represent the geometry of this deposit both on underwater condition or subaerial condition (Fig. 6). The competence of laser to pass through both water and air substance would also be the benefit of this method. The shape of circular atoll-like with the diameter of around 50 cm could be perfectly mimicked in DEM result. This DEM opened the opportunity to observe the more detail morphodynamic behaviour of a laboratory-scaled laboratory. Quantitative measurement of underwater deposit that will be challenging in real life could be measured more easily thanks to this digital elevation model.

Furthermore, the next previous study focused on the shape of an underwater wave ripple sedimentary. The benefit of underwater measurement of this feature is maximized in this example where the water depth of 10 cm would not hinder the depth acquisition process by the laser distance meter. Almost symmetrical feature of wave ripple could be observed both on the section of the flume and also on the DEM (Fig. 7). This high coherency between these two results (photo and DEM) was caused by a simpler sedimentary structure. Where the feature elevation is much more complex, higher resolution of the scale is needed.

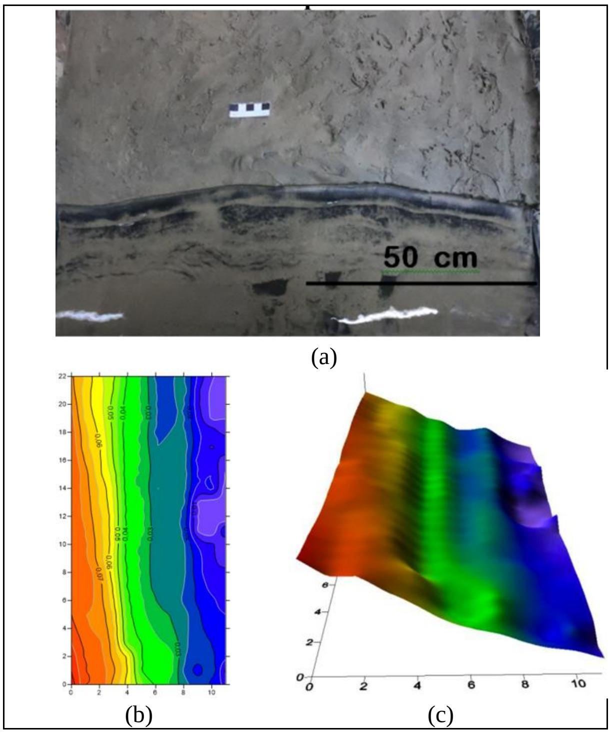

Fig 5. Result of the previous study on coastal plain laboratory-scaled deposit (a) aerial photo taken from above the deposit. The scale of 50 cm was presented in the photo (b) map view of the same deposit acquired in this study (c) 3-dimensional eleveation model of the respective deposit using Surfer® kriging interpolation method

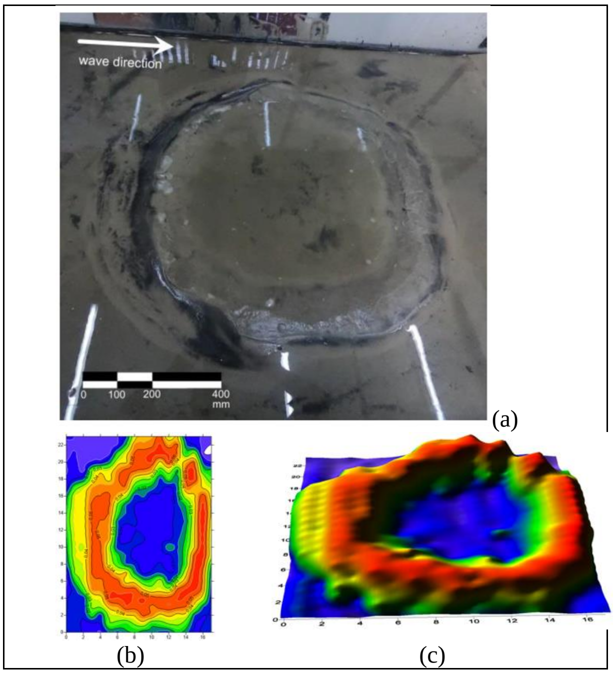

Fig 6. Result of the previous study on atoll-like laboratory-scaled deposit (a) aerial photo taken from above the deposit. The scale of 40 cm was presented in the photo (b) map view of the same deposit acquired in this study (c) 3-dimensional eleveation model of the respective deposit using Surfer® kriging interpolation method

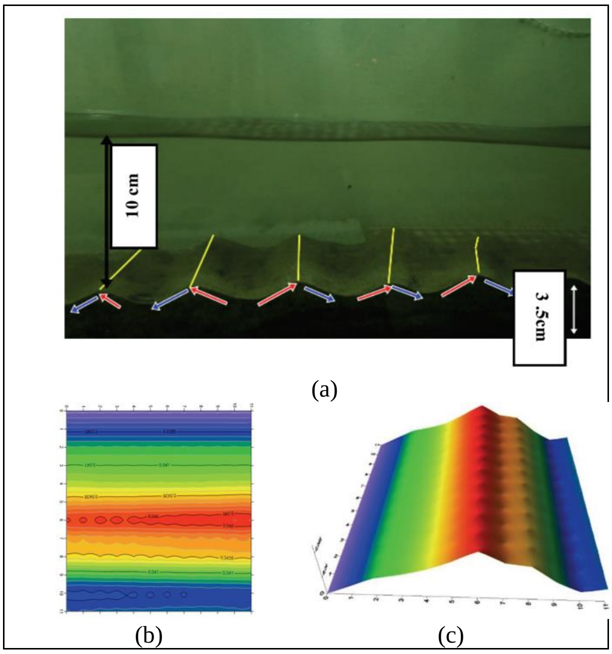

Fig 7. Result of the previous study on wave ripple laboratory-scaled deposit (a) aerial photo taken from above the deposit. The scale of 10 cm was presented in the photo (b) map view of the same deposit acquired in this study (c) 3-dimensional eleveation model of the respective deposit using Surfer® kriging interpolation method

5. Discussions

There are some points that should be considered in using this method such as tool's resolution, financial benefit in using this method, and also the practicality of using laser distance meter in order to build a reliable digital elevation model.

Regarding the tool's resolution, the laser distance meter used in this study has ±2mm accuracy. Nevertheless, human error in moving the laser distance meter will affect a lot in the uncertainty produced in this procedure. A millimetre movement versus a centimetre movement in the designated scale was quite challenging even though a fixed rail had been designed in this experiment. An automatic motor movement of this laser along the scale will give more reliable resolution. This solution might be conducted in order to improve this system.

Another benefit of using this method is mainly the relatively low-cost compare to other laser scanner. All the material used in this experiment are extremely cheap and could be found quite easily in Indonesia. Compare to the more high-technology laser scanner such as Breuckmann Smartscan® that could start the price from \$20.000-\$50.000, in this system we could build the complete system of around \$65 (Table 2).

Table 2. The total cost of building cost-efficient digital elevation model using laser distance meter in a flume tank experiment.

Materials	Spesification	Price		Quantity	Total Price	
		Rp	USD		Rp	USD
Iron pipe	½" Diamter, 6m Long	275000	20,00	1	275000	20,00
Pvc Pipe	¾" Diamter, 6m Long	50000	3,00	1	50000	3,00
T-Shape pepe socket	¾" Diamter	5000	0,35	8	40000	2,8
Pack of screws	-	10000	0,70	1	10000	0,70
PVC Glue	-	35000	2,45	1	35000	2,45
Drawer Railtrack	Double Barelled Stainless Steel rail 20cm	500000	34,50	1	500000	34,50
Laser Distance Meter	-					
					Subtotal	64,8

Regarding the benefit and the challenges that we faced in using this method, using laser distance meter in building digital elevation model brings more benefit especially in a morphodynamic study. Observation of sedimentological structure could be closely scrutinized using this method (Fig. 7). In the other hand, by having a digital elevation model, quantification of a deposit or a morphological change could be directly observed using this method. Nevertheless, time consumption in each acquisition to data presentation could take up to 1-2 hours for each digital elevation model. This time constraint could be diminished in the near future once the automated motor to move the laser distance meter on the designated scale is done. Another improvement in automated data input from the laser distance meter to excel or Surfer® data processing could cut the time consumption in to approximately 50%.

6. Conclusion

In conclusion, by using this inexpensive tool to create a digital elevation model in a flume tank experiment setup, some challenges and benefits will follow this method. Some challenges including tool's resolution and time consuming could be diminished in the near future by creating automated motor system to move the laser distance meter sequentially. Automated and integrated system from the LDM to the processing software could also reduce the time consumption. In the other hand, some benefits including financial benefit, reliability in a sedimentary structure scale, and also the practicality to be applied in any flume tank system available in Indonesia.

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