23

OVERVIEW OF CURRENT LIDAR FILTERING ALGORITHMS AND FILTERS TEST FOR URBAN FLOOD APPLICATION

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ABSTRACT

Urban flooding is serious problem around the world and more severe in South East Asia because of heavier rainfall, increase of impervious area and lower standard of drainage system. The use of accurate hydrological and hydraulics model to simulate urban flooding is essential in order to understand the phenomena and help decision makers to identify suitable solution in order to reduce it. Digital elevation model (DEM) is one of the important input parameter in urban flood application because it will affect flow direction, flow velocity, flood extend and flood depth. LiDAR offer accurate DEM for large area within short time. Manual filtering (classification) pose the

greatest challenge; it consumes an estimated 60-80% of processing time. Urban flood application needs to have accurate representation of DEM in order to produced accurate simulation result. The research will focus on improving filtering algorithm to produce best DEM for urban flood application.

1.0 INTRODUCTION

Urban flooding is an inevitable problem for many cities around the world. South-East Asia regions have more severe problems because of much heavier local rainfall and lower drainage standards (Mark et al., 2004). In order to understand and reduce the flooding, it is important to simulate the urban flooding mechanisms, which consist of flow on surface area, flow in drainage system and flow in underground structure to describe the real flooding process in urban area. Now in developing countries, afford has been made to use advances computer technology to tackle this problem. Local and minor flooding problems are illustrated using computer-based solutions by building the computer models for their drainage and sewer system. These models are then used to give more understanding of the complex interaction between rainfall and urban flooding. Good understanding of the existing condition gives advantages to evaluate alleviation schemes and also to choose the most optimal scheme to be implemented to solve the flooding problem. In conventional models, usually only one part of the urban drainage system is simulated, this is either surface flow or underground sub-system. These models do not represent the real situation, which should have a dynamic interaction between surface and sub-surface flow. In order to improve these conventional models, accurate input data and advanced modelling techniques such as 1D-2D coupling model is really needed.

When dealing with such phenomenon as urban flooding, an accurate model is essential (Vojinovic and van Teeffelen, 2007a). 1D-2D coupling model is a technique to describe the dynamics interaction between surface and underground sub-system. It does not only represent the 1D model of the drainage and sewer system, but also represents the flow in the street, housing areas and depression land in 2D model. This modelling approach can improve the result accuracy and can lead to better understanding and better assist in decision-making. The model will be more reliable if the input data was accurate. Digital elevation model (DEM) is very important input data in flood simulation. This is because it will affect flow path, flow velocity, flow direction, flood depth and flood extend. Until now, LiDAR could offer accurate DEM data for large area within short time. The accuracy of DEM is around 15 cm (Robert Burtch, 2002). For the production of DEM, manual filtering (classification) and quality control pose the greatest challenge, consuming an estimated 60-80% of processing time (Flood, 2001). Another problem is most of the filters parameters are chosen to extract as many objects points as possible, even object that are small and close to the ground. The downside of this is that many valid bare earth (DEM) points could be removed (Sithole and Vosselman, 2004). The consequences of floods and flash floods in many parts of the world have been devastating over the past decades causing extensive tangible damages but also unprecedented loss, personal pain, and social disruption (see for example, figure 1).

This paper presents the results from an ongoing research work, which attempts to develop LiDAR filtering algorithm for urban flood application. Discussion is focus on effects of DEM in urban flood application, using LiDAR for urban flood application, review on LiDAR filtering algorithm and qualitative assessment of Kuala Lumpur LiDAR data.

Figure 1: Kuala Lumpur flash flood, normal water depth is around 2m (left image) but within few hours the water depth is more than 10m (right image).

2.0 DEM AND LIDAR FILTERING ALGORITHM FOR URBAN FLOOD APPLICATION

Haile and Rienjes (2005) mentioned in their paper, representation topography of the river and floodplain is really important aspect for hydraulic flood modelling. Low resolution DEM normally useful for rural area. However in urban area that the DEM is not suitable because a lot of features like road, dykes, building and river bank will affect flow dynamics and flood propagation (results shown in figure 2). Schumann et al. (2007) compare DEM from LiDAR, topographic contours and SRTM with 1D hydrodynamic HEC-RAS model to produce information about water stages during flood event. The different DEM data were validated using reference elevation data distributed across the low-lying flood prone area. The conclusion from the research is LiDAR data are at present is the most reliable source to reproduce topographic data. Sithole and Vosselman 2004 compare eight different filters on total of eight test sites (four urban and four rural). Eight algorithm's developers used their filter on the dataset. The filters work acceptably well in overall aspect but still have problem in two different situations. First is to identify detached objects such as ramps, second is to detect the discontinuity in the bare earth surface. Based on the comparison, there are two algorithm works better in terms of extracting surface (DEM) from LiDAR data. The algorithm is from G. Sohn and P. Axelsson. There are several researches issues discussed in the paper such as full automation is not possible and there are difficulties observed in complex landscape. Suggestion to overcome the issues is by using better algorithm and could thus improve the reliability of automatic filtering. Other suggestions to improve filtering algorithm are by using more context, used of using additional information, landscape decomposition, self-diagnosis and finally automatic filter selection and tuning.

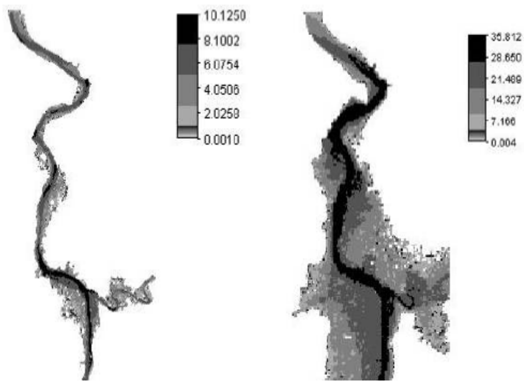

Figure 2: The different simulation results for 5 m (left image) and 15 m (right image) DEM resolution (Haile and Rienjes)

3.0 FLOOD APPLICATION USING LIDAR DATA – CASE STUDY: KUALA LUMPUR

The study area comprises part of the Klang River basin. It is located on the west coast of Peninsular Malaysia in Federal Territory of Kuala

Lumpur (see Figure 3). LiDAR data for the study area was taken in 2003.

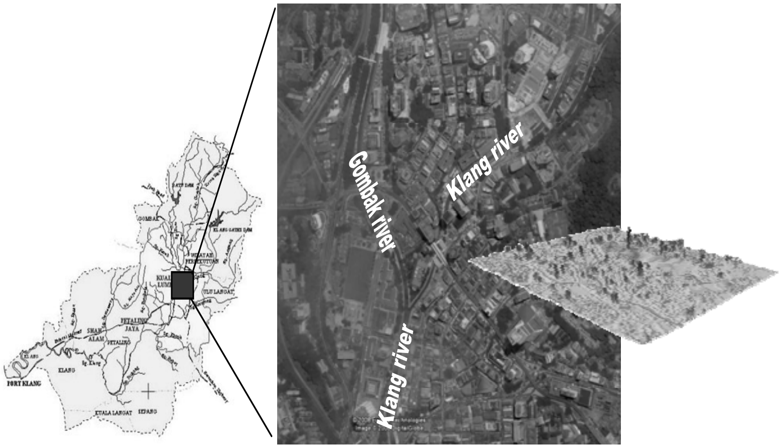

Figure 3: Part of Klang and Gombak River in the Kuala Lumpur city centre (Study area)

A hydrological model for the study area was set up using MIKE 11 modelling software (a product of DHI Water & Environment), which is capable of simulating the system hydrodynamics. Overland flowpaths were based on 2.5 meter grid DEM of interpolated from LiDAR data. Same as for the hydrological modelling, the software MIKE 11, has also been used for hydraulic modelling.

The hydrodynamic module (HD) of MIKE 11 provides a library of computational methods for steady and unsteady flow in branched. The model used to develop the image (see figure 4) is called MIKE FLOOD. The model solves the fundamental equations of fluid motion over a uniform mesh of grid size 2.5 m, using ground levels from DEM. The model simulates flow in the Klang River and tributaries and overtopping of flow onto the streets of Kuala Lumpur. It also simulates rainfall falling directly onto the streets. The simulation is dynamic, which means the flood event from start to finish is modelled.

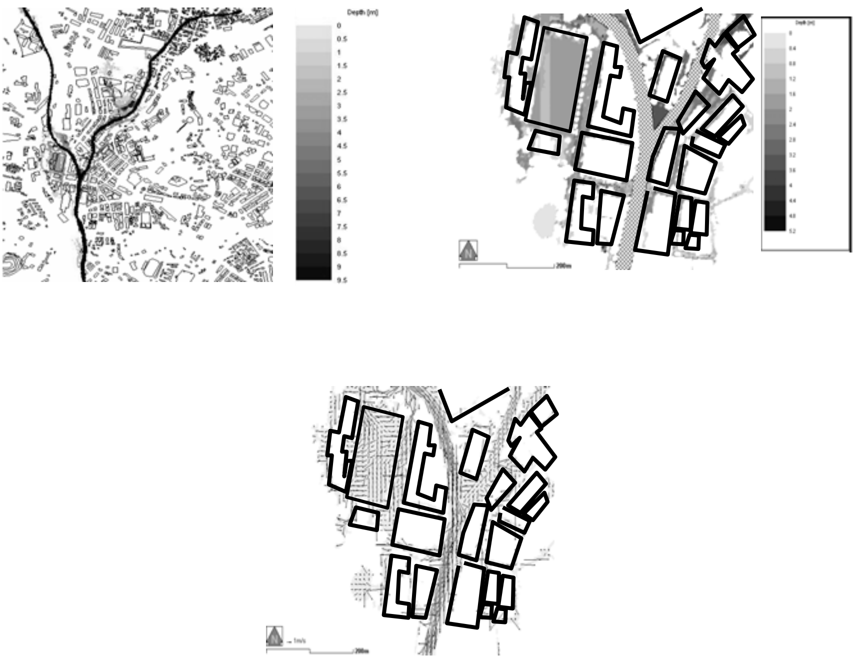

Figure 4: Flood simulation results for Kuala Lumpur city centre by MikeFlood and WaterRide

The modelling activity is a skilled activity that is now fortunately becoming widely distributed, and a considerable body of experience is being accumulated in this area. Robustness and accuracy continue to be issues that affect the modelling, especially when there is uncertainty in the results. Such uncertainties would normally further propagate through to the decision-making. Some of the efforts aimed at dealing with such uncertainties are presented in Vojinovic (2007b), Vojinovic and Solomatine (2006), Vojinovic et al. (2003) and Abebe and Price (2003). The flood visualisation component of a GIS technology is designed in a way to enable engineers and emergency response planners to become familiar with the potential behaviour of flooding (see figure 4).

4.0 EVALUATION OF FILTERING ALGORITHMS

In order to do the evaluation, an open source software ALDPAT (Zhang and Cau, 2007) and commercial software TerraScan are being used. In ALDPAT software, there are eight difference algorithms that can be use for LiDAR filtering while there is one in TerraScan software. Each algorithm has it advantage and disadvantage in performing DTM that suitable for flood model. List and some description of the algorithms are stated in table 1.

Table 1: LiDAR filtering algorithms

Filter name	Description
Elevation Threshold with Expand Window (ETEW)	Elevation differences between neighboring ground measurements are usually distinct from those between the ground and the tops of trees and buildings in an area of limited size. Therefore, elevation differences in a certain area can be used to separate ground and non-ground LIDAR measurements. The elevation threshold method uses an expanding search window to identify and remove non-ground points
Maximum Local Slope	This filter is develop base on differentiate between the slope seen between the ground and the tops of trees and buildings. This slope difference is used to separate ground and non-ground measurements from a LIDAR data set.
Adaptive TIN (ALDPAT)	The Adaptive TIN filter employs the distance of point on the surface of a TIN to select ground points from a LIDAR data set. This filter was developed by Axelsson (2000) and its basic is implemented in the commercial LIDAR data processing software TerraScan
Adaptive TIN (TerraScan)	This filter is base on adaptive tin filter but has been improved to get better result.
Iterative Polynomial Fitting	Previous algorithms separate ground and non-ground measurements by removing non-ground points from a LIDAR data set. Alternatively, LIDAR points can be classified by selecting ground measurements iteratively from the original data set. The iterative local polynomial-fitting algorithm adopts this strategy.
Progressive Morphology	Mathematical morphology uses operations based on set theory to extract features from images. Zhang et al. (2003) developed a progressive morphological (PM) filter to remove non-ground measurements from a LIDAR data set. By gradually increasing the window size and using elevation difference thresholds, the PM filter removes the measurements for different sized non-ground objects while preserving ground data.

5.0 RESULTS AND ANALYSIS

Each filter results have been analyzed in two ways. First, the result will be analyzed qualitatively and then followed by quantitative analysis.

5.1 Qualitative assessment

Based on the results of each algorithm, a list was made of circumstances under which the filter algorithms can produce the best DTM that suit best in urban flood model. In order to get the accurate result in urban flood modeling the DTM should represent the surface as close as possible. In additional, the building and bridge should be removed while objects like ramps that give impact in flood flow should be remained. For this analysis, 5-sub area has been used to visually assess the performance of the algorithms in several difficult terrain types, which include object complexity, attached objects and vegetation on slope as shown by figure 5. These situations relate to capability of algorithm in removal objects/building, the removal of bridge, the capability to capture ramp and removal of vegetation especially on slope. More in detail, the examined cases are described below.

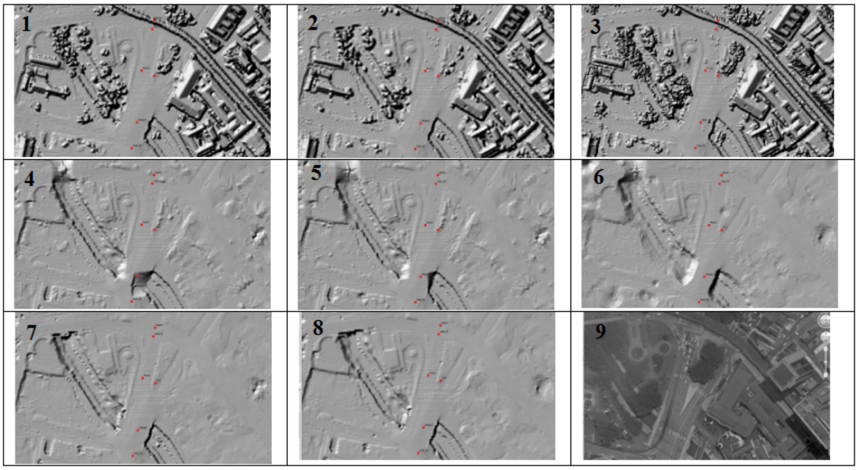

Figure 5: Filtering results; (1) Polynomial 2 Surface, (2) ETEW, (3) Slope, (4) Morphology, (5) 2D Morphology, (6) Polynomial, (7) Adaptive TIN TerraScan, (8) Adaptive TIN ALDPAT, (9) Google image

Adaptive TIN by TerraScan filter is good in removal the objects which in urban environment usually related to the building. The removal of the building is quit smooth and do not effect much the terrain. This filter also has a capability in removal vegetation on slope that usually exist in the riverbank. It removed the vegetation so that the river can be capture clearly with acceptable elevation. It is quit well in detecting ramp where it can show the continuity of the ramp clearly compare to other algorithm. One disadvantage is this filter does not remove bridge, which is one of the important issues in urban flood model. In overall this algorithm can produce good DTM compare with others.

The polynomial 2 surface filter is very good in capturing object, which was not good if we see it in urban flood application context. For the use of urban flood model, the terrain, so-called bare earth is more important than objects. Beside that it can capture ramps; this filter does satisfy the urban flood DTM. It does not have the capability to remove buildings, bridge and also vegetation on slope. In overall, this filter is not good in producing DTM but it is suitable when 3D scene of the area is needed.

Similar to polynomial 2 surface filter, slope filter also does not have capability in removing buildings, bridge and vegetation on slope. In fact this filter is worst than polynomial 2 surface filter. Only ramp can be capture to satisfy the urban flood DTM. In overall this filer is better to be used in reconstruction of the scene of the area in 3D.

When compared with polynomial 2 surface filters and slope filter, ETEW filter give the worst performance in detecting object and building. It is seen that this three filters fell in a same group. Just like the other two filters, this filter also does not have capability to remove building, bridge and vegetation on slope. In overall this filter does not suitable to be use as a filter to produce DTM for urban flood model.

Adaptive TIN by ALDPAT filter has a capability to remove vegetation on slope. It can capture ramps but it is not good in capturing objects or building. The capability in capturing objects and building is worst than TerraScan. The removing of objects is not smooth so that it can affect the accuracy of the DTM. When it meets thin and tall object like flagpole, it create the so-called pond in the scene. This situation certainly represents false information and it can affect the accuracy of DTM produced.

Polynomial filter has some degree of capability to remove bridge and vegetation on slope. The removing of these objects sometime not perfect. When it came to complex building or building on slope, this filter can not detect and can not remove its completely. This situation gives effect to the terrain. It has problem with steep slope where in this situation sometimes the object that not suppose to be there is created. This will certainly reduce the accuracy of the DTM. Similar with adaptive tin filter, this filter also have problem with thin and tall objects like flagpole.

Morphology filter has all capability that can satisfy the DTM for urban flood model. It can remove building, bridge and vegetation on slope. It can also well in detecting ramps even though sometime discontinuity between ramps can be found. It can handle steep slope quit well and can solve pole problem better than adaptive tin filter and polynomial filter. In overall this filter can produce medium level of DTM for urban flood model.

2D morphology filter has capability to remove bridge and vegetation on slope but it failed to remove building smoothly. This situation affects the accuracy of DTM. Besides that it can handle the pole problem quit well and also can detect ramps as needed.

5.2 Quantitative assessment

The quantitative assessment was done by comparing the height of objects that have been filtered through algorithms with the real height. Equation 1 has been used to evaluate the filters accuracy. This comparison can give a clear result on which algorithm can detect one object and which one is not. Please note that in this study the best result is justify base on which algorithm can satisfied the most to produce DTM for urban flood model. In this assessment, three objects were selected to be test, which are divider, bridge and train (LRT) line.

$$RMSE_{Filter} = \frac{\sqrt{\sum_{i=1}^{n}(H_f - H_o)}}{n} \quad (1)$$

Where H_f = height from filters, H_o = observed height

Divider is important in urban flood model because of its physical that can affect the flow of urban flood in urban surface. In this case, the best algorithm should be able to detect the divider with acceptable height. From the table 2 it is seen that all algorithms can detect divider quit well. The divider detected by the algorithm gives the height that very close to the real height.

Table 2: Accuracy of each filter

Filters Object	ATIN - TerraScan	ATIN - ALDPAT	Morph	2D Morph	Poly	Poly 2	Slope	ETEW
Dividers	0.268	0.264	0.273	0.294	0.270	0.292	0.291	0.291
Train lines	0.167	0.157	0.153	0.157	0.169	1.711	1.740	1.694
Bridges	0.322	0.321	1.028	0.986	1.109	0.331	0.324	0.324

In urban flood model, bridge should be removed so that it will not block water flow in the river. From the table 2, five from eight algorithms are seen to have capability in removing the bridge from the scene. Only three filters namely Morph filter, Morph2D and polynomial filter have capability to detect bridge with acceptable height. But as discussed before even though these three filters are good in detecting bridge, but in urban flood context this three filters algorithm is useless.

Similar with bridge, train (LRT) line need to be clear from the scene. It is because the train (LRT) line is usually located above the roads. If it is detected, it will affect the urban flood flow under the train line. From the table 2, it is clearly seen that polynomial filter, slope filter and ETEW filter have capability to capture the train line, which is not good in urban flood context. Others algorithms seem quit well in removing the train line but sometime the removing process is not clean and can affect the DTM.

6.0 CONCLUSIONS

From previous analysis, it is seem that the analysed algorithm can be divided into two groups. One with the high capability to detected objects and the other groups with more focus on terrain/bare earths. If compared with all algorithms in this study, Adaptive TIN from TerraScan filter is seemed to produce the best DTM for urban flood model. Besides the best result, there are some factors like the clean removal of bridge and stable capability in handling building on slope should be improved.

Generally, each algorithm has their advantage and disadvantage. For example, polynomial filter, even though it has capability to remove bridge and vegetation on slope, but the removal action is not clean and can affect the height of the terrain. In the other hand, for example polynomial 2 surface filter, it has high capability on detecting objects like bridge and building but this capability do not give much impact in producing the best DTM for urban flood model.

As discussed before the accurate DTM is very important in urban flood modelling because it will help simulation model to define correct flow path, flow velocity, flood depth and flood extend. Filtering process is really important to be study because it will determine how accurate is the DEM and it is really time consuming.

From the assessment on existing algorithms it is seen that there are no such algorithm that really fit the urban flood model need. The advantage and disadvantage from the algorithm can be use and improved in order to develop the filtering algorithm that specialty for urban flood use.

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