LIDAR FILTERING ALGORITHMS FOR URBAN FLOOD APPLICATION: REVIEW ON CURRENT ALGORITHMS AND FILTERS TEST

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ABSTRACT:

Digital terrain model (DTM) is one of the important input parameters in urban flood application. This is because it influences the flow direction, flow velocity, flood extend and flood depth. LiDAR offers accurate DTM for large areas within a short period of time. From the overall LiDAR data processes, filtering (classification) poses the greatest challenge. Evaluation and comparison of current filtering algorithm is(are) done to find out which one can best filter the LiDAR data in order to develop an accurate DTM that suits the urban flood application. We have tested eight different algorithms. The results have been analysed in a qualitative assessment (i.e.: visually assessing the performance of the algorithm in several terrain types) and then followed by a quantitative analysis (i.e.: height comparison) using the RMSE formula. The result is then used in flood simulation by using MikeFlood software to see the outcome of filtering process to DTM and finally to the flood model. Accurate results in urban flood application depend on how close DTM can represent the urban surface. Objects like buildings and bridge should be removed while objects like ramps which give impact to the flood flow should be maintained. From the overall results and assessment, the advantages and disadvantages of each filter are analysed to formalize a new assumption for the new filtering algorithm that is suitable for the urban flood application. This paper also explains the next tasks, which are to focus on improving the filtering algorithm to detect bridges using geometric method and implementing procedures to remove the bridges during DTM generation.

1. INTRODUCTION

1.1 Background

Flood management for urban areas is a growing precedence due to factors such as the relentless migration to cities, unplanned developments, changing climate, and increasing operational and maintenance costs. The consequences of floods and flash floods in many parts of the world have been devastating over the past few decades causing extensive tangible damages and also unprecedented losses, personal pain, and social disruptions (e.g., the case of Kuala Lumpur, Figure 1). In order to understand and better manage floods in urban areas, it is important to simulate the flood physics, which consists of the flow over surface area (i.e., the floodplain) and the flow in drainage systems (which are often below the ground). Over the past decades, significant efforts were made towards the use of advanced computer technologies to tackle this problem. Physical based computational modelling is invaluable for this purpose. With instantiated models, it is possible to explore the evolution of floods and to simulate the consequent effects in response to any control actions. Vojinovic and van Teeffelen, (2007) have illustrated the use of physically based models which can be applied in identifying structural and non-str`uctural flood management measures. Understanding of the system's function gives advantages to evaluate alleviation schemes and also to choose the optimal scheme which can be implemented in solving the flooding problem. Traditionally, only one part of an urban drainage system is simulated and analysed (Mark et al., 2004). This is either the surface flow or the underground sub-system. Additionally, traditional hydraulic mesh generators focus primarily on physical aspects of the computation grid like aspect ratio, expansion ratio and angle criterion. They often neglect the detailed shape of the topography as provided by LiDAR data (Mandburger et. al. , 2008). However, such model formulations are often insufficient to adequately represent physics of flood phenomena. Along with the developments in computer power, researchers and practitioners have adopted more advanced modelling techniques such as 1D-2D model coupling. 1D-2D model coupling is a technique, which can be used to describe dynamics and interaction between the surface and the sub-surface system. Certainly, with the use of these models, robustness and accuracy continue to prompt issues which affect the quality of modelling work. Some of the efforts aimed at dealing with such uncertainties are presented in Vojinovic (2007), Vojinovic and Solomatine (2006), Vojinovic et.al. (2003) and Abebe and Price (2003). Since the 2D model uses digital elevation data of an area, it is very important that such data is reasonably accurate. Small geometric 'discontinuities' such as road or pavement curbs can play a significant role in diverting the shallow flows that are generated along roads, through fences and around buildings, and therefore, accurate DTM is of a vital importance. In this context, the LiDAR technology is capable of producing relatively accurate DTM data within a short period of time. General literature reports that the accuracy of DTM produced by LiDAR is in the order of ±15 cm. For the production of DTM, filtering (classification) and quality control pose the greatest challenge, consuming an estimated 60-80% of

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processing time (Flood, 2001). In this paper, eight different algorithms were used to process raw data and were discussed in the context of urban flood modelling application. The data processed by using different algorithms were used to set up five 2D floodplain models for the case study of Kuala Lumpur, Malaysia. The models were simulated on one rainfall event for which the flood observation data were found available.

Figure 1. Kuala Lumpur flash flood, normal scene (on the upper image) and flooded scene (on the lower image).

1.2 DTM And LiDAR Filtering Algorithm For Urban Flood Application

It is a widely accepted fact that the generation of the urban surface elevations is not a trivial task (H. lin et al, 2008). It is even more complex when the need to reconstruct complex micro objects such as curbs, ramps and dividers. Periodic structure such as construction cranes also pose a problem in urban environment. In relation to the urban flood modelling work and data requirements, it is often the case that such work requires some objects to be removed and some other objects to be retained. Typically, macro objects such as buildings, vegetation, bridges and flyovers are often made redundant and removed. However, when it comes to micro objects, which have an influence on the evolution of flood flow, then certain features are of greater importance. Generally, reconstruction of urban surfaces can be done in several ways including production of DTM from contours and elevation points. Light Detection and Ranging (LiDAR), also known as an airborne laser mapping or airborne laser scanning, is rapidly gaining acceptance as a tool to generate the necessary data for urban flood modelling work (Mason et al, 2007). High resolution DTM that can be gathered from LiDAR is proved to have a capability to solve problems associated with important small-scale features (a.k.a. as micro features). It also has a capability to solve problems associated with inadequate representation of topographic data. Haile and Rienjes (2005) demonstrated impacts from different resolution DTM data on hydraulic modelling results. It has been demonstrated that the use of low DTM resolution tends to produce shallower depths over larger areas as oppose to the high resolution DTM data, Figure 2. Schumann et al. (2007) comparing DTM to LiDAR, topographic contours and SRTM with 1D hydrodynamic HEC-RAS model to produce information about water stages during a flood event. Different DTM data were validated using reference elevation data, which were distributed, across the low-lying flood prone areas. Sithole and Vosselman (2004) compared different filters for urban and rural area application. It was found that the filters employed could work reasonably well except in two occasions. Identification of detached objects such as ramps, and detection of discontinuities in the bare earth surface were found to impose difficulties.

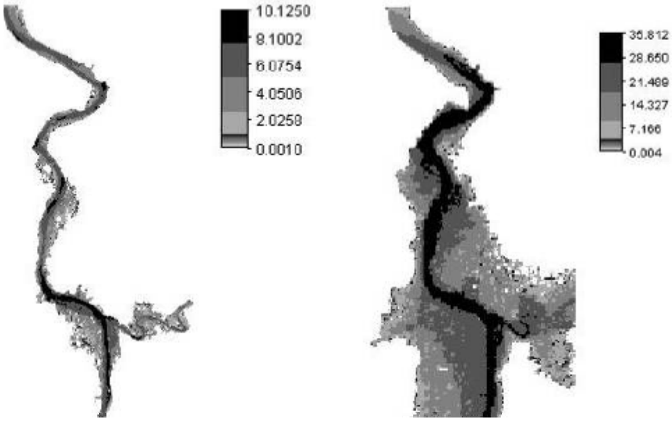

Figure 2: The different simulation results for 5 m (left image) and 15 m (right image) DTM resolution (Haile and Rienjes)

1.3 Study Area

The study area comprises a 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 captured in 2007. 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 1-meter grid DTM of interpolated from LiDAR data. Like the hydrological modelling, the software MIKE 11, has also been used for the hydraulic modelling.

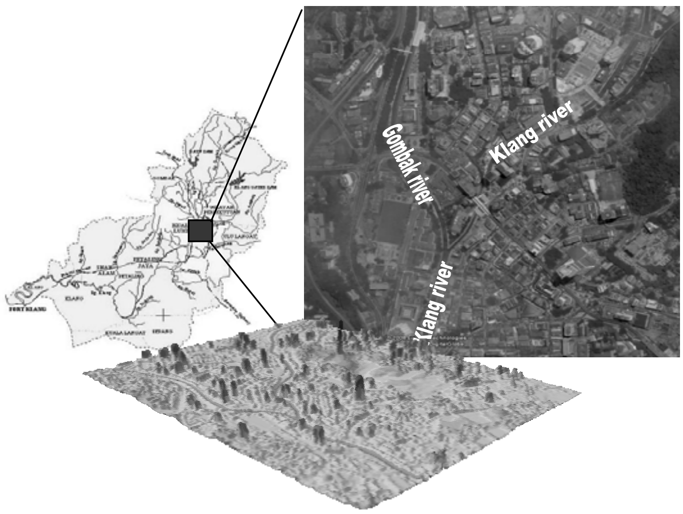

Figure 3: Part of Klang and Gombak River in the Kuala Lumpur city centre (the study area)

The hydrodynamic module (HD) of MIKE 11 provides a library of computational methods for steady and unsteady flow in branched area. The couple model is called MIKE FLOOD. The model solves the fundamental equations of fluid motion over a uniform mesh of grid size 1 m, using ground levels from DTM. The model simulates the flow in the Klang River and tributaries and the 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. The modelling activity is a skilled activity that is now fortunately becoming widely distributed. Robustness and accuracy continue to be the issues that affect the modelling, especially when there is an uncertainty in the results. Such uncertainties would normally be further propagated 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.

2. EVALUATION OF FILTERING ALGORITHMS AND FLOOD MODELLING

In order to do the evaluation, an open source software ALDPAT (Zhang and Cau, 2007) and a commercial software are being used. In ALDPAT software, there are seven difference algorithms that can be used for the LiDAR filtering while there is only one in the commercial software. List and descriptions of the algorithms are stated in Table 1. In order to see the impact of DTM created from the selected existing filtering algorithm to the urban flood model, the filtering result will be interpolated into the DTM format and then be used as an input for the urban flood model.

Filter name	Description
Elevation Threshold with Expand Window (ETEW)	Based on elevation differences between neighbourhoods. Neighbouring ground measurements are usually distinct from those between the ground and objects in an area of limited size.
Maximum Local Slope	This filter is developed based on a diferentiation between the slope seen between the ground and the tops of the trees and buildings.
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.
Adaptive TIN (Commercial)	This filter is based on adaptive TIN filter but has been improved to get better result.
Iterative Polynomial Fitting	This filter classifies ground and objects 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.

Table 1. LiDAR filtering algorithms

2.1 Qualitative and quantitative assessment

2.1.1 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.

For this analysis, a 5-sub area has been used to visually assess the performance of the algorithms in several difficult terrain types, which includes object complexity, attached objects and vegetation on a slope as shown by Figure 4. These situations relate to the capability of the algorithm in objects/buildings removal, the removal of bridges, the capability to capture ramps and removal of vegetation especially on slopes. Adaptive TIN by the commercial software filter is good to be utilized in the objects removal in which urban environment is usually related to the buildings. The removal of the buildings is quite smooth and does not affect much of the terrain. This filter also has some capabilities in removing the vegetation on the slopes that usually exists on the riverbanks. It removed the vegetation so that the river can be captured clearly with an acceptable elevation. It is quite competent in detecting ramps where it can show the continuity of the ramps clearly compared to the other algorithms. One of the disadvantages is that this filter does not remove bridges, which is one of the important issues in urban flood model. In overall, this algorithm can produce good DTM compared to other algorithms. The polynomial two surface filter, Slope filter and ETEW filter are very good in capturing objects but not in removing them. They do not have the capability to remove buildings, bridges and also the vegetation on slopes but it can capture ramps satisfactorily to serve the urban flood DTM. In overall, these filters are not good in producing DTM but it is suitable when a 3D scene of the area is needed.

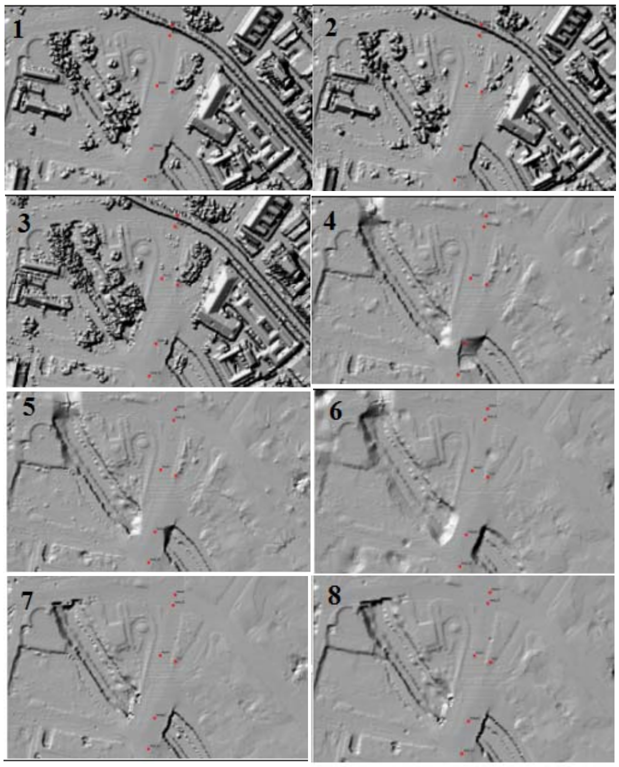

Figure 4. Filtering results; (1) Polynomial two Surface, (2) ETEW, (3) Slope, (4) Morphology, (5) 2D Morphology, (6) Polynomial, (7) Adaptive TIN Commercial software, (8) Adaptive TIN ALDPAT

Adaptive TIN by ALDPAT filter and Polynomial filter has a capability to remove the vegetation on slopes. They can capture ramps. The removing of objects is not so smooth that it can affect the accuracy of the DTM. When it meets thin and tall objects like flagpoles, it creates the so-called ponds in the scene. Morphology and 2D morphology filter have the most capability that can satisfy the DTM for the urban flood model. It can remove buildings, bridges and the vegetation on slopes quite well but sometimes the removing process is not that perfect and gives an impact to the DTM. It performs well in detecting ramps even though sometimes a discontinuity between ramps can be found. It can handle steep slopes quite well and can solve pole's problem better than adaptive TIN filter and polynomial filter. In overall this filter can produce medium level of DTM for the urban flood model. The summary for the qualitative assessment is shown in Table 2.

Filtering Algorithm	A	B	C	D	E	F	G	H
Removal of Object/building	1	4	4	4	3	3	2	3
Removal of Bridge	4	4	4	4	3	3	2	2
Ramp Capturing	1	2	2	2	2	1	1	1
Removal of vegetation on slope	2	4	4	4	1	2	2	2

Where 1= Excellent, 2 = Acceptable, 3 = Fair, 4 = Poor

Table 2. Summary of qualitative assessment. (A)Adaptive TIN Commercial, (B)PolyTwoSurface, (C)Slope, (D)ETEW, (E)Adaptive TIN ALDPAT, (F)Polynomial, (G)Morph, (H)Morph2D

2.1.2 Quantitative assessment: The quantitative assessment was done by comparing the height of objects that had been filtered through the algorithms with real heights. Equation 1 had been used to evaluate the filters accuracy. In this assessment, three objects were selected to be tested, i.e, the divider, the bridge and the train (LRT) line.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2} \qquad (1)$$

where y_i = height from filters
x_i = observed height

Table 3, it can be seen that all the algorithms can detect dividers quite well. The heights of the the detected dividers are very close to the real heights. Five from the eight algorithms seem to have the capability in detecting the bridges.. Three filters namely Morph filter, Morph2D and polynomial filter have the capability to detect bridges with acceptable heights. From Table 2, it is clearly seen that polynomial filter, slope filter and ETEW filter have the capability to capture the train line. Other algorithms perform quite well in removing the train lines but sometimes the removal process is not that “cleaned” thorough and can affect the DTM.

Filters Object	A	B	C	D	E	F	G	H
Divider	0.268	0.292	0.291	0.291	0.264	0.270	0.273	0.294
Light rail train	0.167	1.711	1.740	1.694	0.157	0.169	0.153	0.157
Bridges	0.322	0.331	0.324	0.324	0.321	1.109	1.028	0.986

Table 3. Summary of quantitative assessment. The values in this table were obtained by computing standard statistical measure, RMSE. (A)Adaptive TIN Commercial, (B)PolyTwoSurface, (C)Slope, (D)ETEW, (E)Adaptive TIN ALDPAT, (F)Polynomial, (G)Morph, (H)Morph2D

2.2 Results from flood modelling

Five filtering algorithms have been selected to produce DTM, which are then used as an input in the urban flood models. Each DTM from each filtering algorithm has been analyzed by comparing the flood depths and the flood extent from the urban flood model results with the real flood depths and flood extent at several stations in the study area. In this research, the event recorded was on the 29th October 2001. The verification data (recorded flood depth and flood extent) was obtained from the Drainage and Irrigation Department of Malaysia (DID) report.

Monday, October 29,2001 Time: 6:20pm			
Location	**Depth(m)**	**No of houses**	**Remarks**
Jln Melaka	1.37	10	Dangerous Level
Jln Raja	0.37	5	Dangerous Level
Kg. Kastam	0.57	20	Dangerous Level

Table 4. Flood information

From the DID report, the flood depth was captured on the 29th October 2001 at 6.20 pm at several stations. The relevant flood information obtained from the report is shown in Table 4. Figure 5 shows the results from each filter algorithms.

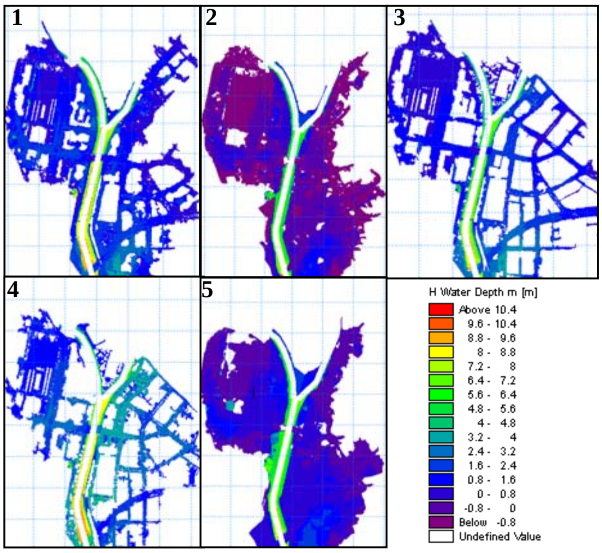

Figure 5. Urban flood model simulation using DTM from ETEW (1), Morph2D (2), Poly two surface (3), Slope (4) and Adaptive TIN (5) on 29 October 2001 at 6:20 PM

2.2.1 Result and analysis for flood depth and flood extent in “Jln Melaka”: As shown in Figure 6 and Table 5, it can be seen that there is no flood occurrence in “Jln. Melaka” from the flood simulation from *Poly two surface* and *Slope* filtering input. This situation occurred because *Poly two surface* and *Slope* filtering algorithm do not have the capability to remove macro objects from urban surfaces. These remaining macro objects have blocked the flood flow and thus influence the flood extent. In this case, the flood does not reach the recording station.

As for *ETEW, Morph2D* and *Adaptive TIN* filtering algorithm, all of them show flood depth lower than what is recorded. This is possibly because of the location of the station is quite far from the centre of the flood. Even though *ETEW* filtering algorithm does not have the capability to remove macro objects, the capturing of these objects is worse than the *Poly two surface* and the Slope filtering algorithms. So less perfect objects are captured and this results to less blockage in the flood flow. Less blockage in the flood flow then results a wider inundation area. The Same situation goes for *Morph2D* and *Adaptive TIN* filtering algorithms. The difference is that these two filtering algorithms have the capability to remove macro objects to some extent. This capability gives even less blockage to flood flow. The fact that these two filtering algorithms (*Morph2D* and *Adaptive TIN*) give lower reading of the flood depth in "Jln. Melaka" compared to *ETEW* is because most of the macro objects are removed from the DTM and resulting the flood to be distributed more evenly around the study area.

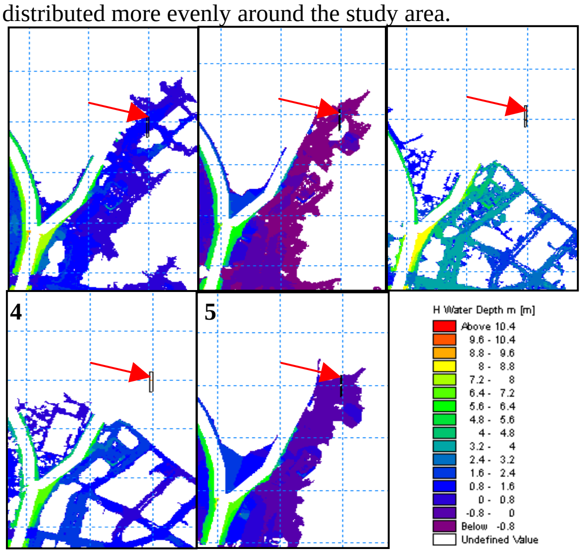

Figure 6. Result from ETEW (1), Morph2D (2), Polytwosurface (3), Slope (4) and Adaptive TIN (5) at Jln Melaka

2.2.2 Result and analysis for flood depth and flood extend in "Jln Raja":

For flood simulation in Jalan Raja (Figure 7), it seems that all the filtering algorithms except *Adaptive TIN* give higher flood depths than the recorded data. *ETEW* and *Morph2D* flood simulation give higher reading of the flood depth in "Jalan Raja" if compared to *Poly two surfaces* and *Slope* flood simulation. This result is expected to be reversed because *Poly two surfaces* and *Slope* filtering algorithms do not remove macro objects and will block the flood flow. This blockage should result in high flood depth.

The result is reversed in this case because the blockage from macro objects in *Poly two surface* and *Slope filtering algorithms* have made the inundation area smaller than the inundation area resulted from the *ETEW* and *Morph2D*. In this case, the flood flow for *Poly two surfaces* and *Slope* flood simulation has just reached the area at the recorded time because of station ("Jalan Raja") is located almost at the boundary of the overall flood area combining with the objects blockage that the flow should face. This situation resulting low flood depth as shown in Table 5. For this case, the flood simulation from *Adaptive TIN* gives the closest result as the recorded data. This is because its capability in removing macro object is better than *Morph2D* and the resulting DTM more likely to represent the urban surface of the study area.

Filters Object	A	B	C	D	E	F
Jln Melaka	1.37	1.11	0.59	0.00	0.00	0.43
Jln Raja	0.37	0.71	0.71	0.47	0.47	0.33
Kg. Kastam	0.57	1.15	0.99	1.04	1.42	0.79

Table 5. Summary of analysis for flood depth and flood extend. (A)Recorded, (B)ETEW, (C)Morph2D, (D)Polytwosurface, (E)Slope, (F)Adaptive TIN ALDPAT in meter

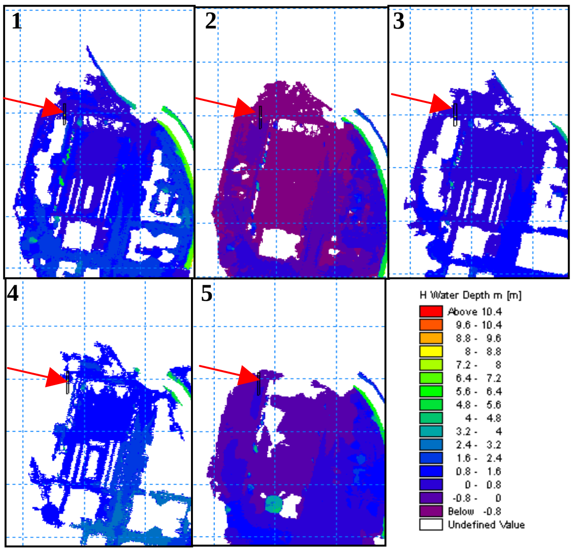

Figure 7. Result from ETEW (1), Morph2D (2), Polytwosurface (3), Slope (4) and Adaptive TIN (5) at Jln Raja

2.2.3 Result and analysis for flood depth and flood extend in "Kg. Kastam":

For the case of the flood depth and flood extent in Kg. Kastam (Figure 8), the result from all the filtering algorithms are as expected. All of them give high reading of flood depth because of the remaining macro objects that caused the flood flow blockage. In this case better results can be obtained if more macro objects are removed from the DTM. In this case, once again *adaptive TIN* gives the closest result in comparison to the recorded data

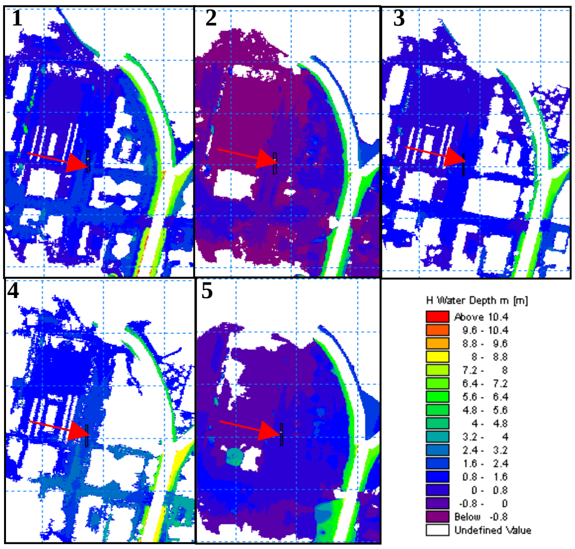

Figure 8. Result from ETEW (1), Morph2D (2), Polytwosurface (3), Slope (4) and Adaptive TIN (5) at Kg Kastam

3. FILTERING ALGORITHM FOR FLOOD APPLICATION AND DEVELOPMENT PROCEDURES

In general terms, the urban flood modelling application requires that the generation of a DEM fulfils the following two objectives:

- The Removal of macro objects (such as buildings, vegetation, bridges, flyovers, light rail train line)
- The Retention of micro objects (such as curbs, ramps, dividers)

The above objectives can be achieved by adopting the so-called 'fusion framework'. Such framework requires three different data sets to be used: LIDAR data, topographic map and land survey data. Within that framework the development process is divided into two major parts. The First part is to remove unwanted macro objects from the LIDAR cloud points. Usually, this part is carried out by applying the adaptive TIN method. The Adaptive TIN filter is good in detecting and removing macro objects such as buildings, vegetation on slopes (which typically exists on the riverbanks), etc. One disadvantage is that this method does not have the capability of removing bridges. After the macro objects such as buildings and vegetation are removed, the remaining points are then overlapped with the bridges and flyover polygon area from the topographic map to get the bridges and flyover boundary area. The selected points are then further classified based on the following assumptions:

- The minimum points in a neighbourhood belong to ground measurement,
- Elevation differences between neighbouring ground measurements are usually distinctive from those between the ground and the objects in an area of a limited size,
- Terrain slope is usually different from the slope as seen between the ground and the objects,
- The perimeter of each non-ground segment is mostly higher than its neighbourhood ,

After this classification process, most of the objects detected will be the bridges and flyovers because the classification area has been narrowed only to the bridges and flyover of surrounding area. These two objects are then removed. The remaining points will then be combined again with the points before the overlapping process is done. The Second part of the development process is to detect and reconstruct micro objects including curbs, ramps and dividers. In this part, the remaining cloud points from the first part will be classified using the segmentation process based on the same assumption (as indicated above). Once the micro objects are detected and labelled, it will be draped with land survey map that has detailed design of curbs, ramps and divider in that specific area. The overlapping process is done to check if discontinuities happen in micro objects. When discontinuities are detected, new points will be created (the same density and height compared with its neighbourhood). This process is called the reconstruction of micro objects. The result from this is expected to be the most suitable DTM for urban flood application (Figure 9).

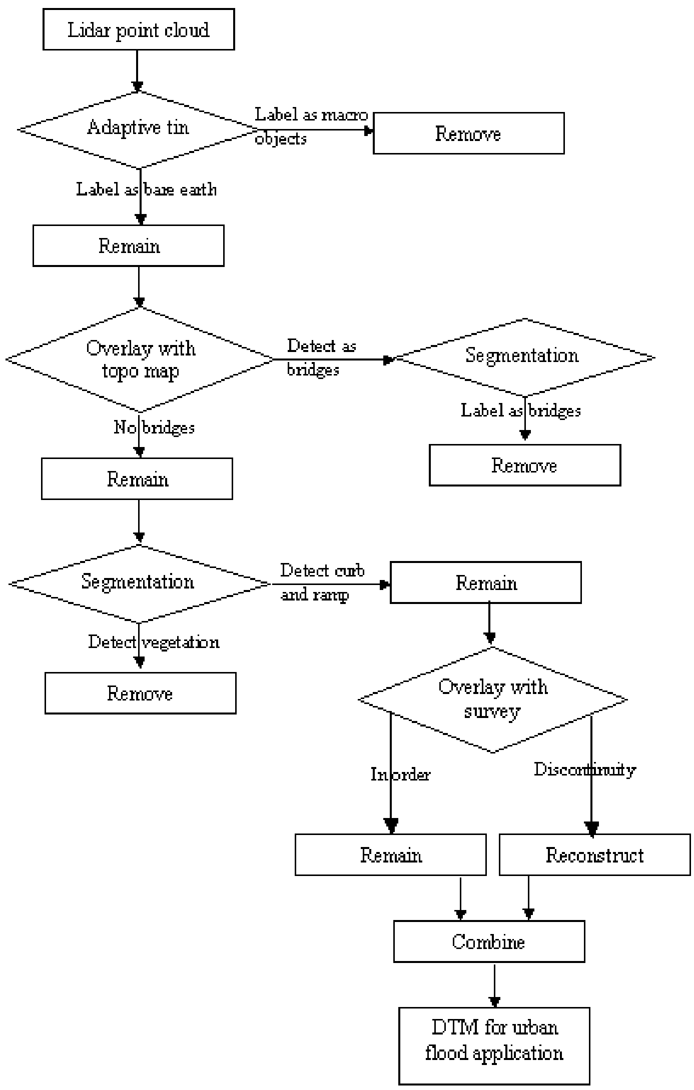

Figure 9. Flowchart for filtering algorithm

4. CONCLUSIONS

In the work described here, eight different algorithms were used to process raw LiDAR data for an urban area in Kuala Lumpur, Malaysia. Such data were used to set up five different 2D floodplain models of the same area in order to investigate the suitability of different algorithms for the urban flood modelling application. The model results were analysed and compared on three sites for which observations were taken during the flood event, which occurred in October 2001. The results have shown that not all of the evaluated algorithms are capable of producing reliable DEM data that can be equally suitable for the urban flood modelling work. From the overall analysis of the results, it can be concluded that the adaptive TIN filtering algorithm has more promising capabilities then other algorithms tested in the present work.

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