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MERGING TOP-VIEW LIDAR DATA WITHSTREET-VIEW SFM DATA TOENHANCE URBAN FLOOD SIMULATION

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ABSTRACT

Top-view data obtainedfrom LiDAR systemshas long been used as topographic-input data for urban flood modelling applications. This high-resolution input data has considerable potential to improve urban flood modelling predictions with more detail. However, the difficulty of employing top-view data is that it may create some missing urban features because this type ofdata cannot represent anyurban features,which are hiddenunderneath other objects. These hidden featuresmay play a substantial part in diverting floodwater flowing through,especially in complex urban areas. The recent advances in Photogrammetry and Computer Vision techniques offer an opportunity to create high-resolution topographic data. By using a consumer digital camera, 2D digital photoscan betaken from different viewpoints. The so-called Structure from Motion (SfM) techniquecan usethese overlappingphotos and reconstruct theminto3D point-cloud data with a high level of accuracy and resolution,usinga cost effective approach. In this work, we create street-view SfM point-cloud data obtained from street viewpoints. We also introduce a new multi-view approach by merging top-view LiDAR data withstreet-view SfM data. This new multi-view data can be used as topographic input data for a coupled 1D-2D model. When applyingsuch newdata, the flood simulation results can highlight some flood propagations much better than using the traditional top-view LiDAR data. Therefore, it has the potential toenhance the multi-view approach into practicable flood-modelling applications for the present and future urbanizing areas.

INTRODUCTION

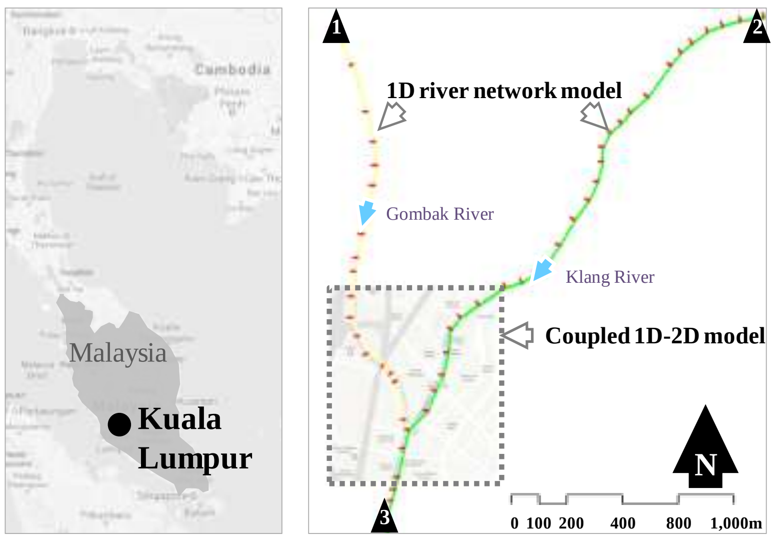
Concerning topographic data, small changes in model resolution can have considerable effects on inundation propagations andpredictions[1]. In urban areas, floodwatersnot only find theeasiest way to flow down to lower paths, but buildings and obstructions also influence them.Small changestoelevation surfacescan have a profound impact of processes in floodplain areas [2].Topographical information is probably the most essential source of input data and a Digital Elevation Model (DEM) is commonly used as topographic input data for flood modelling. DEMs with high resolution and accurate representationof detailsare needed for the performance and reliability of urban flood simulations [3].

Airborne laser scanning (ALS) or Airborne Light Detection and Ranging (Airborne LiDAR) has long been used to obtain data from top-viewpoints. However, when using top-view LiDAR data, the break-lines of building footprints may be reshaped or hidden by other structures or vegetation. Such hidden footprints may misrepresent alleys, kerbs, and pathways and these may play a significant role in diverting flows[4], producing misleading flood-map simulation results[5].

By applying the so-called Structure from Motion (SfM) technique, the overlap of 2D digital photographs can be used to create 3D point-cloud data from different viewpoints[6]. To get a better representation of topographic data, a new multi-view approachhasbeen proposedin this work. Thismulti-viewapproachmerges the top-view LiDAR data withstreet-view SfM data. Themerged multi-view datacan be finally used to createa new multi-viewDEM, which was used as input data forthe urban flood modelling setup in this case study.

DESCRIPTION OF THE STUDY AREA

Kuala Lumpur (KL), the capital city of Malaysia, is crowded with an estimated population of over 3.6 million. This complex cityis located at the confluence of the Klang River flowing from the northeast to the south, and the Gombak River from the northwest conjugating to the Klang River in the middle of the city. This city experiencedconsiderable floods and flood-related damage on 10 June 2003. In this work, asmall case study of 0.4 $km^2$was selected for the coupled 1D-2Dmodelling(see Figure 1b).



(a) (b)

Figure 1.(a) The city of Kuala Lumpur, Malaysia; (b) The coupled 1D-2D modelling schematization (the background is from GoogleMap).

CREATION OF DIGITAL ELEVATION MODELS

The top-view LiDAR DEM

Aerial Light Detection and Ranging (Aerial LiDAR) is widely used to create accurate and dense elevation data obtained from top-viewpoints. LiDARbeams and measuresthe properties of scattered light from ground surfaces.In this work, the LMS-Q560 LiDAR system was set and mounted on a Bell-206b Jet Ranger helicopter. The helicopter flew at an altitude of ~700 m, a ground speed of ~51.4 m/s, and a side lap of 40% for each flying path. The Global Positioning System (GPS) data and the Inertial Measurement Unit (IMU) data wereused to refine the raw LiDAR data.Then, therefined LiDAR data provided an average point-cloud density of ~2.4 points per meter with an absolute accuracy of ±0.05 m in the horizontal direction and approximately twice the vertical direction. Finally, a top-view LiDAR DEM (Figure 2)wascreatedat 1 m gridded resolution by using MikeZero[7].

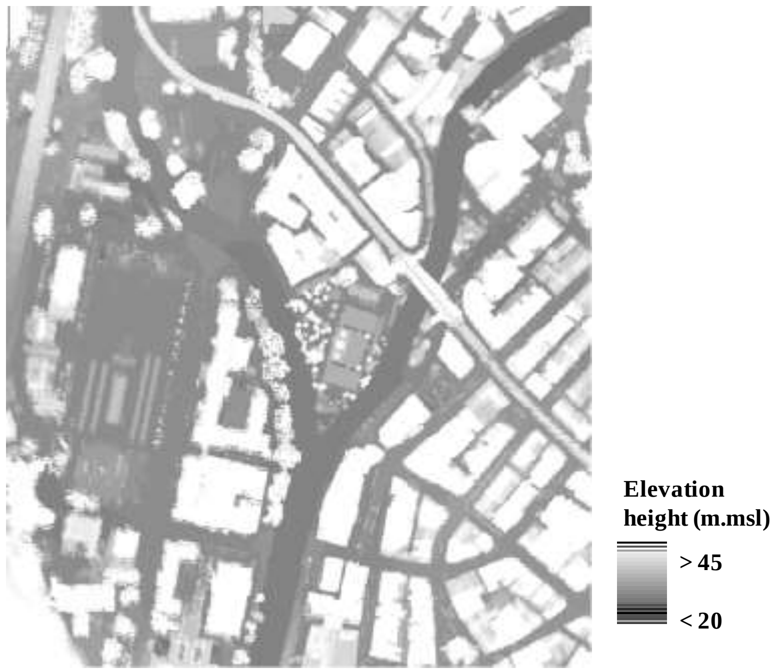


Figure 2. A top-view LiDAR DEM shows the Skytrain track running from the northwest to the southeast.

The street-view SfM data

By employing computer vision techniques with advanced photogrammetry, it is possible tocreatehigh-resolution topographic dataat sub-metre precision[8]. The so-called Structure from Motion (SfM) technique is an outstanding technique in this field capable of creating very high-resolution topographic data. Unlike the traditional stereo photogrammetry technique, the simplicity of using the SfM technique is that a number of overlapping photoscan be taken by using consumer digital cameras, which can be easily mounted on cars, mopeds, or used as a handheld device.

A Nikon D5100 digital single-lens reflex (DSLR) camera has been used to capture the scenes from street viewpoints. Twenty five thousand photos were taken at 1920 x 1080 pixels along JalanTun Perak Road. Althougha Vibration Reduction (VR) system was set to stabilize a Nikkor 18-55 mm lens, some blurry scenes were still recorded due to camera motion or object movements. The subsequent removal of blurred photos was undertaken manually. To process the point-cloud data, a laptop running 64-bit Microsoft Windows 7 equipped with 8 cores Intel i7 CPU at 2.20 GHz, 16 GB of RAM, and 2 GB Video RAM embedded in NVIDIA GeForceGTX580M graphics cards was applied forPhotoScan[9]. Nine distinct ground control points (GCPs) in the LiDAR dataset were used to reference the coordinate positions of thestreet-view SfM data (Figure 3). The absolute errors in producing the street-view SfM data were found to be in the order of ~18 cm (RMSE in the GCP data).

(a) (b)

Figure 3.A streetview shows some urban features hidden underneath aSkytrain track: (a) a street-view photo scene and (b) an example of street-view SfM data.

The multi-view DEM from the top-view LiDAR data andstreet-view SfM data

To recover the hidden urban features, a new concept using amulti-view approach has been introduced in this work. This new approach is able to merge different data sources with different viewpoints. This new concept allows (hidden) urban features to be reconstructed by substituting one viewpoint with another. The top-view LiDAR data and the street-view SfM data were then merged to create a new multi-view data by using in-house python scripts and MeshLab. Finally, a multi-view DEM was created at 1 m gridded resolution by using MikeZero (Figure 4).

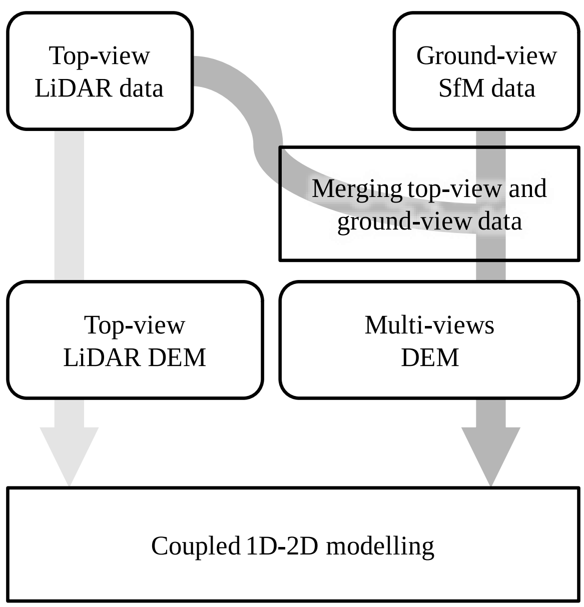


Figure 4. Approaches tocreating DEMs for coupled 1D-2D urban flood modelling

The example of the multi-view DEM shown in Figure 5 demonstrates that merging the top-view LiDAR data with street-view SfM data can benefit from both large area coverage by the topviewpointsand alsoa high level of detail of the street viewpoints.

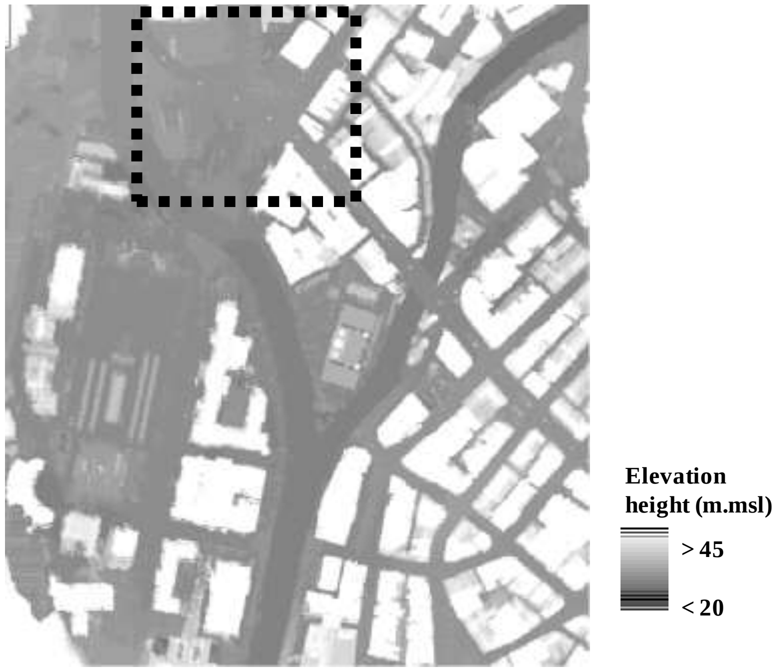


Figure 5. A multi-view DEM shows somepillars, pathways, and kerbs underneaththe Skytrain track.

URBAN FLOOD MODEL SETUP

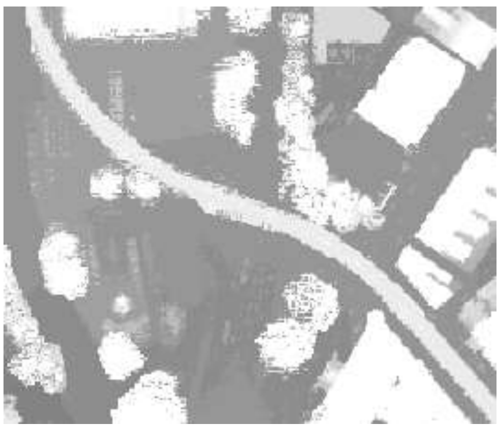
A coupled 1D-2D modelwas developed to investigate the propagation of excess floodwater from the two main rivers (the Klang and Gombak Rivers) into the 2D urban area (Figure 1b), using the DHI MikeFlood[10]. The flood event of 10 June 2003 was used. The boundary conditions represent discharges at JalanTunRasak and JambatanSulaiman stations (marked “1” and “3” in Figure1b, resp.) and the water levels at Lorong Yap Kwan Seng station (marked “2” in Figure1b).A Manning friction coefficient of 0.020 was applied uniformly to the constructed 1D channels, following the criteria defined by Chow[11]. A Manning coefficient of 0.033 was also used for the 2D urban surface area, applied identically to each of the three DEMs. Six measurement locations recorded by the Department of Irrigation and Drainage (DID) were used in the evaluation of the flood simulation results[12].

RESULTS AND DISCUSSIONS

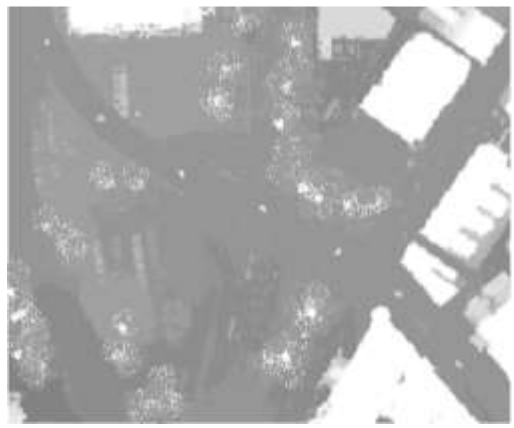
In this work, the two different DEMs, a top-view LiDAR DEM and a multi-view DEM,havebeen used as input data for the coupled 1D-2D numerical model setup. In Figure 6a-1, the top-view LiDAR DEM shows the Skytrain track running from the northwest to the southeast, although an earlier study by Abdullah et al. [13] mentioned that some filtering algorithms can replace the high features of the Skytrain track with ground-flattened elevations. However, it is not possible to correctly create or reconstruct the small urban features hidden underneath. In Figure 6b-1, the multi-view DEM shows some pillars, pathways, and kerbshidden underneath the Skytrain track.

In a sub-domain marked as a dotted area in Figure 1b, the waters start to overflow from the Gombak River to the riverbank toward the northeast direction. These also show that the floodwaters primarily propagate along the riverbanks, roads, and pathways downward to lowland areas.When using the top-view LiDAR DEM as input, the Skytrain trackis seen to behave as a dike. The floodwaters seem to propagate only in the southern part and no floodwater appears in the northern part of the domain (see Figure 6a-2).

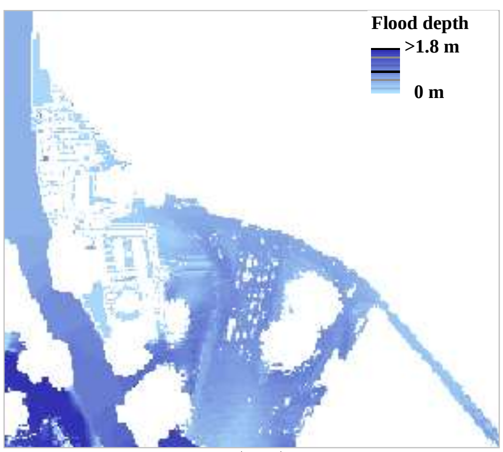
When applying the multi-view DEM as input, the floodwater propagation can be much betterrepresented. This new multi-view DEM can highlight even small details of urban features, which can still play a significant role in diverting shallow floodwaters. In Figure 6b-2, it is observed that small kerbs underneath the Skytrain track can play a significant role in diverting and confining floodwaters flowing along the road.The dotted line also shows a hidden flood area.It can be noted that applying such multi-view data can represent more details, and it also indicates more flood areas, whereasanother DEM cannot.



(a-1)



(b-1)



(a-2)

(b-2)

Figure 6.Two different DEMs were usedas input for the urban flood modelling setup: (a-1) a top-view LiDAR DEM and (b-1) a multi-view DEM. The two simulated results: (a-2) using the top-view LiDAR DEM and (b-2) using the multi-view DEM.

CONCLUSIONS

In the case study presented here, a coupled 1D-2D numerical modelling approach was used to simulate the extreme urban flooding event that occurred on 10 June 2003 in Kuala Lumpur (Malaysia).The two different Digital Elevation Models (DEMs) were derived from top-view Light Detection and Ranging (LiDAR) data and street-view Structure from Motion (SfM) data. From the analysis, it was found that when employing the top-view LiDAR DEM the flow patterns and water depths may not have been correctly represented in the flood map. Some overarching structures such as a Skytrain trackaretypically perceived as obstructions for floodwater propagation.

These obstructing features could be removed by applying some filtering algorithms to the top-view LiDAR data. However, in such filtered data the obstructing features can only be replaced with the surrounding ground-flattened elevations. They do not contain particular urban features hidden underneath. Nevertheless, such hidden urban features can have a considerable effect on floodwater dynamics and predictions. This work shows that the SfM technique can be effective in representing hidden urban features, e.g. alleys, pathways and kerbs, when obtaining the data from the street viewpoints. By merging the top-view LiDAR data with the street-view SfM data, a new multi-view approach can be very beneficial for flood modelling applications.Correspondingly, the numerical flood simulation results were found to be agood representation of the floodwater dynamics.

It can be concluded that the new multi-view approach of merging top-view LiDAR data with street-view SfM datacreates a more accurate DEM with more details, which can be used as input data for a numerical urban flood model simulation. When employingthis multi-view DEM, the simulation result can illustrate a more realistic representation of floodwater dynamics and inundation extents. Future work infusing remotely sensed data from SfM-based surveys to create both top-view and side-view photos isalready underway, thus enabling a rapid setup of numerical flood models over larger domains.

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