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LiDAR DEM Data for Flood Mapping and Assessment; Opportunities and Challenges: A Review

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Abstract

Flooding is the most catastrophic, wide spread, and frequent natural hazards causing extensive damages on infrastructure, human life, and the environment. The frequency and severity of flooding has been increasing all over the world attributed to climate change and escalated urbanization. As such, the issue and techniques of monitoring and mapping flood inundated areas are also increasing. Advancement of state-of-the-art technologies have facilitated and improved flood mapping and monitoring. Earth observation plays important role in flood mapping, monitoring, and damage assessment. However, there are fundamental issues that restricts satellite data from being used for flood studies. LiDAR DEM data based flood modeling approach solves some of the limitations of Earth observation. On the other hand, flood modeling using LiDAR DEM data are challenging. The aim of this review is, therefore, to identify the opportunities and challenges of using LIDAR DEM data for flood mapping and assessment. Substantial literature review was done to attain the stated objective. The study revealed that flood modeling techniques could significantly improve the limitations of detecting flood using Earth observation such as detecting flooded areas under dense canopies and in urban areas. This is attributed to the accurate and fine resolution LiDAR DEM. Furthermore, LiDAR technology provide several opportunities such as relatively cost and time effective data collection system, capability of penetrating dense vegetation, and improved flood model accuracy and fine scale flood modeling. On the other hand, LiDAR data filtering (classification), data availability and accessibility, data file size, high computational time, inability to characterize channels bathymetry, and insufficiency of representing complex urban features are some of the challenges. Therefore, multi-platform LiDAR data (i.e., ground-based, airborne and space borne) and data from additional sources such as echo soundings and electronic theodolite surveys should be integrated to increase the effectiveness of the LiDAR technology for flood modeling.

Keywords: Flooding; LiDAR DEM data; Opportunities; Challenges; Flood modeling

Introduction

Flooding is the most catastrophic natural hazards causing extensive damages on infrastructure, human life, and the environment. It is also wide spread and frequent natural disasters in most parts of the world including the developed countries [1-5]. For example, flooding accounts 40% of all deaths resulting from natural catastrophes [6]. The effect is high in developing and tropical regions due to poor infrastructure, limited coping mechanisms, and lack of early warning system (Table 1). The frequency as well as the severity of flooding has been increasing all over the world attributed to climate change and increased urbanization [7].

Regions		Flood occurrence	Total deaths	Total affected (Millions)	Total damage (Million USD)
Region I	Asia	712	46452	1148.8	214237
	Africa	473	9263	38	4591
	Caribbean, Central and South (CCS) America	346	10484	31.2	19097
Region II	Europe	255	1108	6.9	63589
	USA and Canada	82	362	11.6	33025
	Oceania	43	125	0.59	11062
Total		1911	67794	1237.09	345601

Table 1: Global flood disaster occurrence and its impact from 2000 to 2015 [27].

As a result, the issue as well as techniques of monitoring and mapping flood inundated areas are also increasing. Flood mapping and monitoring have been facilitated and improved with the advancement of remote sensing and geographic information system [1]. Particularly, the application of Earth observation techniques for flood monitoring and delineation are reported by many studies [1,5,8,9]. Optical and radar Earth observation systems provide valuable information for observing and delineating the flood-affected area, assessing flood damage, and provide input data for flood modeling. However, there are fundamental issues that restricts satellite data from being used for flood studies [9]. For example, optical remote sensing is incapable of detecting flood under clouds and vegetation as it is affected by them. On the other hand, relatively microwave remote sensing (i.e., Radar) can observe flood under cloud and vegetation. However, dense forest still hinders flood detection using Radar system [8]. Moreover, Radar data are more expensive and difficult to be interpreted and analyzed. According to Sanyal and Lu [1], wind induced waves in the water surface frequently creates problems for interpreter to determine the threshold value in delineating flooded area from Radar data. Generally, spatial and temporal resolutions of Earth observation is course relative to the spatial scale and duration of flooding. Furthermore, the system has limited capability to penetrate dense vegetation. As such, Earth observations (i.e., both optical and microwave remote sensing) are limited for accurately detecting and mapping flooding. Moreover, Earth observations are also limited to precisely detect flooding in complex urban landscapes.

Flood modeling techniques could significantly improve the limitations of detecting flood using Earth observation such as detecting flooded areas under dense canopies and in complex urban areas [5]. Digital Elevation Model (DEM) is one of the most important input parameters for flood modeling. As such, the reliability and accuracy of the model is highly dependent on the accuracy and resolution of the DEM data [1]. DEM resolution and accuracies highly influences flood simulation results such as inundation extent, flow velocity, flow depth and flow patterns [3,10]. Accurate and high-resolution DEM data can produce most accurate and reliable flood inundation map compared to the course and inaccurate DEM [3,10,11]. Therefore, accurate and high-resolution DEM data are required for reliable flood mapping. Airborne Light Detection and Ranging (LiDAR) technology provide dense and accurate elevation data which could improve the performance of flood modeling studies [12]. However, LiDAR DEM data have some limitations such as huge data size, pre-processing of the data, computational time, and availability and accessibility of the LiDAR data.

Therefore, the aim of this study is to assess the opportunities and challenges of using LiDAR DEM data for flood modeling. The remaining part of this paper is organized in to four sections. Section 2 describes the general overview of LiDAR technology. Section 3 describes opportunities of LiDAR DEM data for flood modeling. Section 4 deals with challenges of using LiDAR DEM data for flood modeling. Section 5 presents conclusion and draw recommendations for the way forward.

LiDAR Technology

LiDAR is an active remote sensing that produces highly accurate and dense elevation data which are suitable for flood modeling [13]. LiDAR system uses a laser scanner mounted on ground, aircraft or satellite. The system releases discrete pulses from the laser, record time required for the pulses to travel from the scanner to ground targets and calculate distance between the pulses and targets. An airborne LiDAR system is typically composed of three main components: a laser scanner unit, a Global Positioning System (GPS) receiver, and an Inertial Measurement Unit (IMU). The instantaneous position and orientation of the laser with respect to the ground can be determined using the Global Positioning System (GPS) and Inertia Navigation System (INS) on board platform. Additional information on the scan angle and GPS base station are required to construct the 3D position of the ground feature [14].

The vertical accuracy of the LiDAR DEM data ranges from ± 5-15 cm and able to collect terrain elevation at a density of at least one point per 1 m spacing [15]. This imply the horizontal accuracy of LiDAR system is less than 1 m. On the other hand, the vertical accuracies of SRTM and ASTER are 16 m and 20 m, respectively [16]. Therefore, LiDAR system is capable of providing highly accurate, dense point, and high-resolution DEM data compared to SRTM and ASTER system. As such, it is highly suitable for varies applications such as archaeology, structural geology, geomorphology, engineering, resource management, and disaster assessment and planning such as flooding and landslides [14]. The LiDAR DEM is, particularly, suitable for accurate and detail scale flood modeling specially in urban areas and flat topography [5,10,12,17-19].

Opportunities of Using LiDAR DEM for Flood Modeling

LiDAR systems are capable of providing high density and high accuracy DEM data. It is similar with photogrammetry in terms of accuracy. However, Ma [20] argued that LiDAR system can provide more accurate surface measurement than photogrammetry. For example, LiDAR is advantageous in penetrating vegetation canopy and fast data collection system compared to traditional surveying techniques such as photogrammetry [21]. LiDAR system has improved flood modeling techniques via providing accurate and high-resolution DEM data as its reliability is highly dependent on DEM accuracy and resolution [19]. LIDAR DEM data driven flood modeling best performs compared to other DEM data sources [10,22]. Airborne LiDAR DEM data is useful to characterized riverbanks and floodplains morphology and support accurate flood modeling [15].

Moreover, several studies revealed that LiDAR DEM have many advantages which made it suitable for flood modeling. LiDAR data, for example, provide detail topographic information that is widely used in floodplain mapping [4]. Furthermore, LiDAR system is characterized by rapid data collection capability, high degree of automation, high point density, high level of accuracy, and cost efficiency [10,12,20]. According to Bodoque et al. [19], Digital Surface Models (DSMs) derived from LiDAR system improved 1D and 2D hydraulic models, provide valuable data for 2D hydrodynamic models, enable grain-scale surface roughness (an essential parameter in flood modeling), and provide very accurate topographic datasets of both the ground and urban landscapes (e.g., buildings, roads, bridges).

Detail features from the urban landscape and ground are hardly determined from other DEM data such as SRTM and ASTER due to their course spatial resolutions. As such, LiDAR DEM data is highly suitable for flood modeling particularly in flat areas and complex urban environment. Moreover, accurate simulation of hydraulic and hydro-morphological variables could be obtained using high-resolution LiDAR data [17]. In addition, airborne LiDAR can be used to determine water course and water depth of inundated areas [4,5].

Despite several opportunities that LiDAR technology provides for flood modeling methodology, there are challenges in using the LiDAR data for flood modeling. According to Baldassarre and Uhlenbrook [15], high resolution and dense LiDAR data alone does not guarantee accurate flood modelling, there are several challenges that restricts the applicability of LiDAR DEM data for flood modeling.

Challenges of Using LiDAR DEM Data for Flood Modeling

Studies showed that there are challenges in using LiDAR DEM data for flood modeling. According to Zhang et al. [23], the process of identifying and classifying ground from non-ground and removing the non-ground points for Digital Terrain Models (DTMs) generation has proved to be a challenging task. Haile and Rientjes [10] also argued that the important problems in using LiDAR data for flood modeling is to define bare earth elevation that is used in the flood model. Such process is said to be filtering (classification). According to Haile and Rientjes [10], filtering process took about 60-80% of the data processing time. Moreover, it is challenging to select the best filter algorithms as each of them have advantages and disadvantages. Any filtering methods are subjected to commission errors that classifies non-ground points as ground measurements and omission errors that removes ground points mistakenly [23]. Filtering LiDAR data in urban areas area particularly challenging due to the complex urban landscape. Abdullah et al. [23] compared eight filter algorithms for processing raw LiDAR data and concluded that none of the evaluated algorithms are capable of producing reliable DEM data that can be relevant for urban flood modeling. According to the study, adaptive TIN filtering algorithm, however, has more promising capabilities than other algorithms.

According to Abdullah et al. [24], urban features such as roads, curbs, elevated roads, bridges, rivers and river banks are always difficult to be detected by the currently existing filter algorithms. The study tested and proposed Modification of the Progressive Morphological Algorithm 2 (MPMA2) for urban LiDAR data filtering. According to the study, the new algorithm is improved to be applied in urban areas due to their ability to deal with different kinds of buildings, ability to detect elevated road/train lines and represent them in accordance with the actual reality and ability to deal with bridges and riverbanks. In a similar way, Alho et al. [11] argued that LiDAR data preprocessing procedure (i.e., masking) affect the accuracy of detecting riverbank inundation.

The other challenge of using LiDAR DEM data for flood modeling is related to its inability to sufficiently represent complex urban features. According to Turner et al. [12], LiDAR is insufficient to accurately represent the finer scale topographic and complex urban landscapes due to its inability of continuous coverage, it has no information along break lines. The conclusion is, of course, contrary with the idea of Bodoque et al. [19] and Abdullah et al. [24] as described above. The study further proposed additional high resolution data from ground-based LiDAR sensor to supplement the existing airborne data. Such technique could be used to increase the accuracy of flood prediction in topographically complex and sensitive urban areas. The computational time required to handle the LiDAR datasets is also another typical challenge [12].

Furthermore, LiDAR technology have limited capability to penetrate water column and therefore, unable to characterize channels bathymetry (i.e., bed topography) [2,25]. Such limitation is higher for flood assessment if the river flow has suspended sediment load [25]. Therefore, echo soundings and electronic theodolite surveys are required for incorporating bathymetry data into DSMs [26]. Moreover, LIDAR data may not contain important details from a hydraulic point of view due to its systematic sampling procedure [19]. According to the study, LiDAR DEM are unable to detect structures like levees or continuous walls, which are an obstacle to water flow. As such, the study recommended to take the advantages of LiDAR data, but in combination with classic topography survey at conflictive points, enabling suitable representation of elements in the final DSM that may be essential to flow behavior and thus minimizing flood assessment errors.

In addition to the above-mentioned challenges, availability and accessibility of LiDAR DEM data is another limiting factor. Due to the high initial cost and difficulty of handling and processing the huge LiDAR data, it is difficult to have the data at regional and country level. The LiDAR data is not available for the entire country even for the developed countries like in United State of America and United Kingdom [2,15]. The scarcity of the LiDAR data in developing countries are more sever due to economic constraints. As such, it is difficult to get LiDAR data for African regions.

Conclusion and Recommendation

Flooding is the most disastrous natural hazards negatively affecting human life, the environment and the socio-economy of the world. The severity and frequency of flooding has been increasing attributed to climate change and land use change particularly urbanization. As such, much attention has been given for monitoring and mapping flood hazards. Earth observation (i.e., optical and microwave remote sensing) is effective techniques for detecting and mapping flooding. However, their spatial and temporal resolution as well as their inability to penetrate dense vegetation and cloud restricts them from effective flood detection and mapping. Flood modeling which is fully dependent on accurate and high-resolution DEM data solve some of the limitations of Earth observation. As such, LiDAR system improved the performance of flood modeling via providing fine resolution DEM. The opportunities that LiDAR technology provided for flood mapping includes provision of accurate and high-resolution DEM data, relatively cost and time effective data collection system, capability of penetrating dense vegetation, improved flood model accuracy and fine scale flood modeling, adequate representation of man-made and topographic features, and capability of determining flood depth.

On the other hand, LiDAR system are challenging to be used for flood modeling. The major challenges include LiDAR data filtering (classification), data availability and accessibility, data file size, high computational time, unable to characterize channels bathymetry, and insufficiency of representing complex urban features.

Therefore, multi-platform LiDAR data (i.e., ground-based, airborne and space borne) and data from additional sources such as echo soundings and electronic theodolite surveys should be integrated to increase the effectiveness of the LiDAR technology for flood modeling. Moreover, flood modeling should be calibrated with gauge data and validated with remote sensing imagery. More importantly, further researches have to be conducted to improve LiDAR data filtering algorithm particularly that best fit to urban areas.

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