OPEN ACCESS Freely available online

ISSN: 2469-4134
Journal of
Remote Sensing &
GIS

Review Article

Review Paper: Applications of light Detection and Ranging for Flood Modelling and Mapping

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ABSTRACT

Flood is one of the most frequent natural disasters in the world, which make a significant impact all around the world on a regular basis, as a result of increased urbanization and extreme climate change. Because of climate change, unplanned rapid urbanization, changes in land use patterns, and inadequate watershed management, flooding events are expected to become more frequent and devastating in the future. The problems of flood are continuously gaining global attention with substantial efforts are being made to create effective flood control and monitoring solutions. The preparation of flood hazard and floodplain models and maps is of the main concern researcher's and prior area of government's policy in phase in the disaster management and mitigation. As a result, more studies and methods of flood monitoring and mapping are being developed to mitigate the devastating effects of flood disasters, causing the loss of life, livelihood, and infrastructure. The advancement of remote sensing science and technologies such as Light Detection and Ranging (LiDAR) systems with various processing algorithms, facilitated and improved flood assessment applications. The purpose of this review is to look into the potential and uses of a LiDAR derived DEM on different flood vulnerability assessments and inundation mapping. It also goes through the operational principles of various LiDAR systems, as well as the components of each system, and also the challenges of the system from flood assessment perspective. Furthermore, future prospects using DEM LiDAR data in flood mapping and assessment are highlighted.

Keywords: Flooding; LiDAR DEMS; Quality of LiDAR DEMs; Application LiDAR DEMs; Urbanization

INTRODUCTION

The problems of floods are continuously gaining global attention with huge efforts are being made to create efficacious flood control and monitoring solutions. The preparation of flood hazard and floodplain models and maps is of the main concern for researchers and prior area of government's policy in phase in the disaster management and mitigation, which is frequently used to minimize the influence of disasters, reacts during an event, and takes action to recover after a disaster, including other disasters. Flood mapping and assessment require accurate records of river flow data over long periods of time. These observations, however, are subject to high uncertainty, and data is not always readily available. To overcome such drawbacks, Earth Observation (EO) datasets (e.g. space borne, aerial, and satellite images) can be used with Geographic Information Systems (GIS) to estimate flood inundation and develop flood hazard and risk maps. Flood modeling and mapping often involve flood frequency estimation, hydrodynamic modeling, and inundation mapping, all of which requires particular datasets that are frequently unavailable in developing regions due to financial, logistical, technological, and organizational constraints. It has recently benefited from advances in remote sensing technologies and machine learning algorithms. Even when such data and algorithms are handed sufficient ground truth training samples, they may still be unable

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Received: 20-Sep-2022, Manuscript No. JGRS-22-18085; **Editor assigned:** 23-Sep-2022, PreQC No. JGRS-22-18085 (PQ); **Reviewed:** 07-Oct-2022, QC No. JGRS-22-18085; **Revised:** 23-Jan-2023, Manuscript No. JGRS-22-18085 (R); **Published:** 30-Jan-2023, DOI: 10.35248/2469-4134.23.12.281

Citation: Mengesha TE, Belay WA (2023) Review Paper: Applications of light Detection and Ranging for Flood Modelling and Mapping. J Remote Sens GIS. 12:281.

to accurately estimate flood extents. Therefore, climate driven changes are greatly affecting the environment and economy of world, thus, the need for world communities to develop and implement strategies to slow down and militate against the effects of climate change. Developing these strategies require accurate, timely and affordable information. During the last 60 years, a variety of lidar technologies have been developed to provide atmospheric and surface features to support improvement in digital terrain models, cryospheric discovery, terrestrial ecology, hydrology, atmospheric science, and oceanography. It is indisputable that LiDAR is being used in a variety of science research activities, including geology mapping, landslide hazards, and flood risk management. It helps to produce a data that can be used to generate Digital Surface Models (DSMs) and Digital Terrain Models (DTMs) for flood modeling. In the event of a crisis, extremely detailed and accurate information on how far the floodwater inundates and how deep the land is flooded at what velocity is used for floodplain management and flood damage estimation becomes vital to relief efforts and resilience. As LiDAR data is becoming more widely available, which is transforming how organizations prepare for and respond to disasters? The capacity to create high quality elevation models using LiDAR point clouds reduces the time it takes to get accurate information on the ground conditions during a disaster. Only LiDAR can penetrate the vegetative canopy sufficiently to give accurate DTMs when full coverage aerial LiDAR is provided, with RMSE values of less than 0.30 m. DEMs are numerical representations of topography composed of equal sized grid cells or pixels that store elevation data. DEMs are typically interpolated to establish different elevation values for an entire terrain, which is an array of pixels with an elevation value assigned to each pixel based on geographic location. The use of space based remote sensing techniques provides a way for cost effective near real time mapping of flooded areas. These flood maps will become essential to relevant agencies during a flood, as well as landowners and farmers when planning flood for prevention and recovery efforts [1].

LITERATURE REVIEW

Basics principles and fundamentals of LiDAR

LIDAR, short for Light Detection and Ranging (LIDAR), is a remote sensing technology that uses laser pulses to create comprehensive topographic maps and provide digital elevation data for flood modeling and risk analysis (Figure 1). It uses the electromagnetic energy of the optical range to detect an object, determine the distance between the target and the device, and drive the physical properties of the object based on the interaction between the radiation and the target through phenomena such as: Active remote sensing technology. Scattering, absorption and reflectance. LiDAR was first developed in the 1970's to measure the properties of air, seawater, forest canopies, and ice sheets, but not for topographic maps [2].

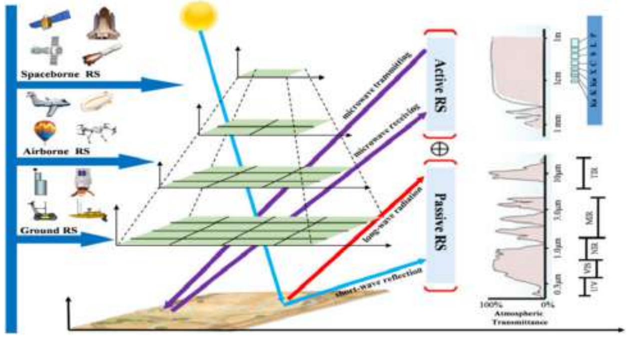

Figure 1: The schematic diagram of LiDAR system.

LiDAR systems are widely used in a variety of applications, such as, evaluate the height and size of individual trees or, at stand level, to estimate forest stand canopy closure, volume and biomass; to assess wildlife habitat; and to quantify fire sensibilities and their benefits are broadly recognized by researchers and practitioners worldwide. LIDAR systems are classified into three types: Ground based, airborne, and space borne. The first LIDARs were on the ground. Terrestrial laser scanners are one of these systems that are commonly used for indoor environment mapping. There is also a newer generation of ground based LIDARs that have been used for atmospheric research. Because of the need to study the vertical structure of the atmosphere at high temporal resolution and on a global scale, space borne LIDARs were developed. Satellite LIDARs have now made it possible to measure the earth's atmosphere from space. Space borne LIDAR satellites provide unique information of various parameters in the atmosphere at the global scale. Following the successful implementation of ground based systems in the 1960's, laser scanners were mounted on aerial platforms. Airborne Laser Scanners (ALS) can capture 3D point clouds, which are primarily used to generate Digital Surface Models (DSM). This system has some flaws, such as aircraft operation costs, flight restrictions, and local data acquisition [3].

A pulsed laser is used in the LIDAR method to measure and record three dimensional information on the earth's surface (topographic LIDAR), the seafloor, or riverbed (bathymetric LIDAR). An airborne LiDAR system is typically carried aboard a light fixed or rotary wing aircraft. The LiDAR technology consists of four basic components for data collection and laser beam orientation such as laser, an Inertial Navigation System (INS) unit that includes an Inertial Measurement Unit (IMU) for correcting the orientation of the mobile platform, the Global Navigation Satellite System (GNSS), and a computer storage unit. When these components are combined into a single device, an integrated surveying system was developed, enabling for the quick collection of large quantities of accurate data in a short period of time [4].

Applications of LiDAR system in flood monitoring

The LiDAR systems are widely used in various applications, such as the estimation of the height and size of individual trees or, at the level of the tree stands, for the assessment of the density, volume and biomass of the tree bed; the assessment of the habitat of wild animals; and the quantification of fire sensitivity.

It is also recognized that the benefits are widely recognized by researchers and practitioners around the world. LIDAR systems are divided into three types: Ground, air and space. The first lidars were on the ground. Ground based laser scanners are one of the systems commonly used for mapping the internal environment. There is also a new generation of terrestrial lidars that were used for atmospheric research. Space lidars have been developed in response to the need to study the vertical structure of the atmosphere with high temporal resolution and on a global scale. Satellite lidars have already done it. In most of developing countries conventional ground stations for monitoring hydrological parameters could be expensive, they do not record occurrences extreme events and may not be cost effective. Remote sensing is an alternate or complimentary source of data for observations, which compensates for the traditional way of data collection restrictions, particularly in remote parts of those developing countries. Satellite data provide comprehensive, synoptic, multi temporal and large spatial coverage in near real time and at frequent intervals [5].

Flood map and models using DEM LiDAR

Ground, air and space based satellite platforms can be used to map surface water bodies and the extent of floods. LiDAR has attracted much attention because of its accurate measurement capabilities, which can now provide middle and high resolution topographical data in 2D or 3D space that can be used to build more complex flood models. Lidar height data were used to input data for flood models such as river cross section geometry, flood topography and flood humping. CMRs derived from data sources other than LiDAR often have more severe spatial resolution and less precision. As a result, the flood area tends to be larger than the results obtained from CMM, which have a more precise spatial resolution. In hydrological modeling, the accuracy of the DEM is critical because it affects discharge values, water depth, and flood inundation maps. For instance, in flat floodplain a vertical error of 1 m in the DEM results in a flood inundation error of 100 km^2. As a result, accurate and high resolution DEM data are required to produce reliable flood mapping, mainly for flood simulation modeling [6].

Techniques of flood modeling could greatly enhance the limitations of flood detection *via* earth observation, such as flood detection in densely canopied areas and in complicated urban settings. One of the most essential flood modeling input elements is the Digital Elevation Model (DEM). There is therefore a considerable dependence on the accuracy and resolution of the DEM data on the dependability and precision of the model. LiDAR can provide high resolution data, which can be utilized to construct Digital Surface Models (DSMs) and Digital Terrain Models (DTMs) for flood modeling. The same study been conducted by Boonya-aroonnet S and Prodanovic D to investigate the influence of DEM resolution on surface flow network for pluvial urban flooding and simulations of integrated system, and they conclude that, the quality of the surface network generated is highly dependent on the quality and resolution of the terrain data sets [7].

Digital Elevation Models (DEMs), the geomorphological and hydrological parameters produced from DEMs have become a recommended tool for identifying flood prone regions. DEMs derived from LiDAR data having high resolution and accuracy were widely used in flood modeling and the water surface elevations and flood maps created using LiDAR data are more accurate than other used DEMs around the world. To improve the accuracy of flood models, high resolution DEMs from different sources are highly preferred.

The use of high resolution LiDAR DEM data is a very interesting approach to flood modelling and assessment and has several shortcomings for flood modelling studies, but it is costly to start with. Niraj Lamicane and Suresh Sharma demonstrate that the modelling of catches and floods using high resolution Lida based data sets, which are also used for detailed watercourses and waterlines. On the other hand, the dissemination of Digital relief Model (DM) data sets, especially those created by laser altimetry or LiDAR, has led to the creation of a rich data environment for flood modelling Sampson, et al. Data from the high resolution on board scanner laser altimeter (LiDAR) Digital topography Model (DM) attracted considerable attention for accurate and sound flood mapping as well as hydrological and hydraulic [8].

Ashleigh B, et al., examined the usefulness of a ground (mobile and ground) high resolution data set for Light Detection and Range Determination (LiDAR) (distance between points 0.2 m), supplemented by a more severe on board data set of LiDAR (5 m). (*i.e.*, point interval) for use in flood analysis. They found that the quantitative comparison of water surface profiles and depth grids using on board data only LiDAR revealed underestimation of flooding, volume and maximum flood height, and the maximum height of flooding increased by 35 per cent as a result of the LiDAR composite data set. In the same study, Colby and Dobson evaluated the results of the modelling of floods using the Digital Terrain Model (DMC) with different resolution regimes and determined that higher resolution terrain was needed to better display flood floods in low species locations. The quality of LiDAR DEM depends on the process of sampling and filtering [9].

According to Riyanto, et al. DSM from LiDAR was used to calculate the potential catchment area of a river with very high contour resolution. They found that the flooding near the riverbank had doubled compared to the original river. Lidar DEMs are preferred over other DTMs for flood modeling due to their high resolution, and also have a higher degree of accuracy and reliability and demonstrate that Lidar DEMs are the best representation of the terrain for flood mapping, giving more accurate results than other available topographic datasets [10].

A study conducted by Luigi L Toda, et al. used LiDAR technology to create a detailed flood map to classify cultivars of specific rice varieties. As a result, adaptation to agriculture may be promoted. Helps strengthen food security in the area.

Parametric 2D hydrodynamic flood models using LiDAR DEM and other DEM products. They found that, compared to current flood maps, the extent of floods simulated using LiDAR DEM was significantly better than those simulated using other DEM products. In addition, penton and overton used LiDAR DEM in combination with a basic GIS based flood model to map the flood inundation of the lower Murray River and found that the simulated output was equivalent to the inundation map obtained from optical Landsat imagery [11].

Matgen, et al., high resolution Light Detection and Range finding (LiDAR) DEM and ENVISAT ASAR multi temporal landscapes were used to determine the depth of the 2003 floods of the Alzette River in Luxembourg. They claim that the flood edges taken from the ASAR images were crossed with LiDAR data to estimate elevations at the boundaries of the water polygons. In addition, Schumann, et al. uses the same method to examine empirical results using various elevation information, namely terrain contours, Shuttle Radar Terrain Mission (SRTM) DEM, and LiDAR based DEM, for higher resolution. I understand that LiDAR data provides better results. In the same way, yellow etc. quantified the depth of the flood using a combination of optical Landsat and LiDAR data, assuming that the horizontal plane can be considered to be clearly flat if the flood area is small enough. For aerial DEM, Podhoranyi, et al., evaluated the generated cross section and its subsequent effects based on LiDAR data coupled with HEC-RAS and 2D hydraulic modeling, flood hazard assessment methods were developed by suing actual and mathematical hydrological data (Figure 2). And they illustrate that, for every urbanized area, a LiDAR DEM based 2D flood simulation is required in light of climate change and today's society development demands and trends [12].

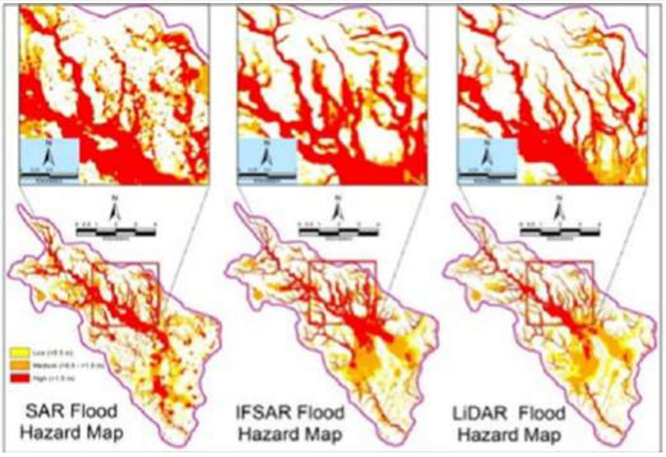

Figure 2: Flood hazard map from various DEMs sources.

Aktaruzzaman M and Schmitt T investigate the application of LiDAR for flood modelling, in addition to DEMs observed from LiDAR, apply LiDAR intensity data for urban flood monitoring. They found and recommend that, practice of using of only aerial images with RGB wavebands is often incapable of identifying types of surfaces under the shadow, in which LiDAR intensity data can provide surface information independent of sunlight conditions. In further, Vorawit Meesuk, et al. assess the urban flood modelling by combining top view LiDAR data with ground view SfM observations. They found that a more accurate digital terrain model can be created by a new multi view approach combining the top view LiDAR data and SfM ground view observations, which can then be used as an input for quantitative urban flood models simulation and generate a more realistic representation of floodplain dynamics and flood depths [13].

Casas, et al., investigated the effect of DEM sources on flood hydraulic modeling in terms of hydraulic model outputs such as flood inundation and water surface elevation. The findings of this study demonstrated that the flood model output was strongly dependent on the DEM quality with LiDAR data, indicating a high potential source for channel and floodplain topography parameterization. Schumann, et al. compared the effect of DEMs generated from airborne LiDAR, contours, and SRTM on a flood inundation model. The results were compared to inundation maps generated by a model that was calibrated using ground surveyed maximum watermarks [14].

In summary, previous research found that accurate terrain data had a significant impact on flood hazard prediction. Various DEM resolutions produced different flood simulation results, which could be associated to the degree of topography represented. High resolution DEMs have been proven to give meaningful and accurate flood modeling outcomes. Previous research has found that accurate terrain data has a significant impact on flood hazard prediction, and that with coarser DEMs, the inundation area is evaluated more accurately.

Accuracy of LiDAR based DEM in case of flood monitoring

DEM resolution and accuracy play an important role in flood inundation modeling in terms of modeling resolution and accuracy. A low resolution DEM, allows for quick model simulations but simplifies topographic information that may affect flood propagation. Because of the presence of small features, high resolution DEMs are required, particularly in urban areas; thus, the resolution of the DEM is likely to affect the accuracy of flood simulations. As a result, many researchers conducted studies to determine whether coarser DEM resolution reduces the accuracy of predicted flood inundation extent [15].

The accuracy of DEMs are depends on the nature of the topography and ruggedness of the terrain as well as the type of vegetation, methods and procedure for collecting elevation data, algorithms and method for DEM generation, type of DEM grid, and DEM resolution. Besides from internal LiDAR system errors, external factors such as flight height, terrain variation, terrain cover such as vegetation type and buildings, sampling angle, and spatial resolution also influence data accuracy. Burke worked on the West Creek area at Toowoomba utilizing a LiDAR dataset that he demonstrated by the performance of a full ground based detailed survey of the area with RTK GPS and confirmed that, the error of between derived grid DEM and DEM from LiDAR of RMSE is 0.260 m.

The spatial resolution of DSM/DEM plays an essential part in terms of the accuracy of flood mapping. DEMs created from data sources other than LiDAR are often coarser in spatial resolution and have less accuracy. In consequence, flooded areas tend to be larger when compared to results obtained using DSMs, which have finer spatial resolution. A high vertical accuracy and horizontal resolution DEM is required for the production of reliable inundation maps. According to Gesch, high accuracy elevation data with high spatial resolution from lidar provide more accurate characterization of inundation zones than other types of elevation data. Saksena and Merwade assessed the accuracy in flood maps caused by DEM attributes such as resolution and precision, revealing that the elevations of the water surface and flood area have a linear relationship with the DEM's accuracy. The results show that the accuracy of the flood maps can be significantly improved by modeling the spatial distribution of the DEM errors. A high vertical accuracy and horizontal resolution DEM is required for the production of reliable inundation maps. According to Gesch, high accuracy elevation data with high spatial resolution from lidar provide more accurate characterization of inundation zones than other types of elevation data [16].

Tamiru and Rientjes investigate the impacts of LiDAR derived DEM resolution on flood modelling. Several DEM's input to the flood model has been used in this work with varied resolutions. The authors found that the DEM resolution has a significant impact on the results of simulations. Additionally, Casas, et al. investigated the effect of different topographic data sources on flood modeling. According to the authors, the accuracy of the DEM has a significant impact on flood modeling results, with a LiDAR derived DEM having the lowest Root Mean Square Error (RMSE) in terms of elevation accuracy and estimated flood inundation (Figure 3). Generally, a low resolution DEM leads to a loss of information and an unnecessary computational time is caused by a high resolution DEM [17].

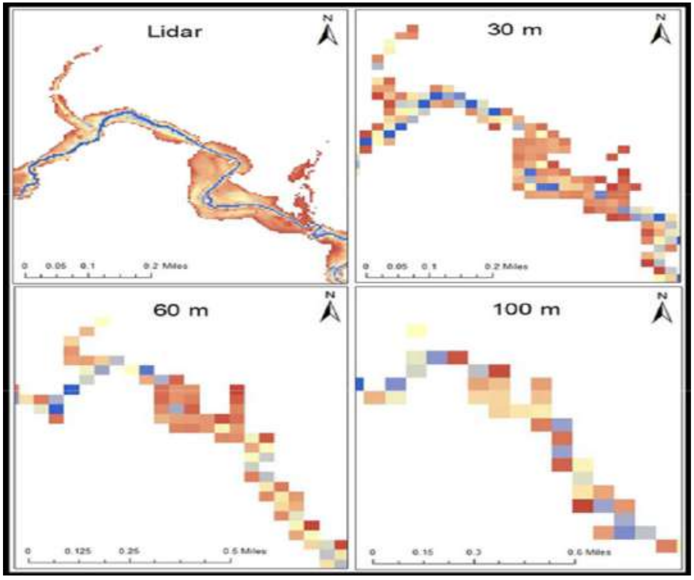

Figure 3: Flood maps generated from different resolution DEMs for Strouds Creek.

Aze, et al., investigated the accuracy and resolution of LiDAR DEMs in order to improve the quality of hydrological features extracted from DEMs. The authors also investigated into the effect of resampling DEM data to a coarser resolution. The results reveal that the input DEM's accuracy and resolution have a significant impact on the values of DEM derived hydrologically indicators. Furthermore, Hsu, et al. analyzed the effect of DEM resolutions on 2D flood inundation simulation in Tainan City's Sanyei drainage area (Taiwan). The authors began with an 1 × 1 m LiDAR DEM and later used it as the foundation for aggregating several DEMs, including 5 × 5 m, 10 × 10 m, 20 × 20 m, and 40 × 40 m. Accordingly, they developed five flood inundation models using the same model settings and conclude that, inundation area increased with coarser DEMs.

Ahmad F Zoran V and Vorawit M describe the discrepancies that can occur when diverse DTM data sets are processed at different grid resolutions and with different LiDAR filtering techniques. This study examined several LiDAR filtering methods and discovered that none of them are factually correct in collecting key important urban features. Furthermore, Wang and Zheng tried to compare LiDAR derived DEM to United States Geological Survey (USGS) National Elevation Data (NED) on floodplains in North Carolina. Sanders supported the scope by comparing LiDAR derived DEM and NED to airborne Interferometric Synthetic Aperture Radar (IfSAR) and SRTM for flood inundation modeling. Sanders confirmed that the DEM resolution had a significant impact on flood model predictions. The author also found that the DEM derived from LiDAR was more accurate than other DEM sources, which overestimated the flood extent. The requirement for LiDAR data is now a critical input to hydrologic and hydraulic models, particularly flood inundation models.

Zhao, et al., investigated the effects of DEM accuracy on hydrological parameters and discovered that at the watershed scale, DEM resolution primarily determined the accuracy of areas and boundaries of sub basins, as well as the distribution of flow lines, whereas actual DEM accuracy had a greater impact on elevation differences. Ariza Villaverde, Jimenez Hornero and Gutierrez de Rave used multifractal analysis to assess the effects of DEM resolution hydrologic modelling. High DEM resolution for high density drainage systems was determined to be crucial, but less important in sparce drainage networks.

Advantage, challenges and future prospects of lidar in flood assessments

LiDAR technology is still advancing rapidly in terms of sensor and data processing. The competition among LiDAR sensor producers is primarily focused on increasing laser pulse repetition rates and vertical spatial resolution in order to collect more data points. The pulse repetition rate has increased from less than 50 KHz in 2001 to 250 KHz. Since the first attempt to use laser for distance measurement, LiDAR has gone through many impressive development stages. Despite the fact that there are many different types of LiDAR systems in use, there are still many technical difficulties to be solved, and new LiDAR systems are being developed on a regular basis.

Although LiDAR technology offers a significant advantage over traditional field surveys in terms of data collecting speed, processing massive volumes of LiDAR point data, which can amount to large numbers of measurements for study area, poses a challenge to the generation of accurate DEM. LiDAR derived DEM provides more details and relatively better topographic information than other DEMS, such as Synthetic Aperture Radar (SAR) and Interferometric Synthetic Aperture Radar (IfSAR), due to its higher resolution.

LiDAR data is captured at any time of day or night, as well as under cloudy conditions. Furthermore, it has a better ability than photogrammetry or IfSAR to penetrate the ground surface in vegetated and urban regions. As a result of these factors, it has recently become a popular solution for flood related issues. LiDAR systems ability to produce higher resolution and centimeter accurate results has boosted their use in flood research over a wide range of applications. While on board modelling of floods using LiDAR data can be generally accurate in rural or homogeneous areas, the impact of complex terrain and features, such as buildings and infrastructure, which affect the direction and flow of flood water in urban environments, can lead to inaccuracy in the creation of flood maps. In order to improve the accuracy of flood forecasts, the inclusion of high resolution data from the LiDAR ground sensors could supplement current aerial photographs in topographically complex or sensitive urban areas, which would help to better alert local residents to their potential hazards. However, the LiDAR technology is limited in its ability to penetrate the water and therefore cannot characterize the bathymetry of the logs.

LiDAR research in the future will primarily focus on the continuing development of new radiation sources, the integration of multi sensor systems and data fusion, and the study of new LiDAR mechanisms. Compared to ground survey or photogrammetry methods, LiDAR technology has made capturing 3D coordinates easier and more efficient. It provides accurate data of the ground elevation and also demonstrates 3D imaging of the elevation.

Airborne lidar has greater precision and accuracy due to its ability to penetrate vegetation and reduce scattering, but it is largely limited to a few countries due to economic constraints and can be expensive to acquire. These properties are useful for producing high quality (1 m vertical error) "bare DEMs" in which objects (such as buildings and vegetation) have been removed from the elevation model. Such exposed DEMs are critical for applications that rely on precise surface features, such as flood modeling.

DISCUSSION

The main drawback of the LiDAR system is the process of trying to separate ground data from non-ground data for the DEM generation required for flood model simulation. Extraction of surface information from LiDAR is difficult in areas with complex terrain and features such as vegetation and buildings. Various ground filtering processes and techniques were performed to obtain information from LiDAR data that could affect product accuracy and be solved by a variety of challenging machine learning algorithms.

Various studies have shown that LiDAR is superior to photogrammetry for creating DEMs in urban areas and does not have the shadow effect of photogrammetry. However, the raw LiDAR data may contain echoes from some other target that the laser beam hits, including artificial objects, vegetation, and even birds. Also, although LiDAR has the ability to penetrate vegetation and reduce spread, it is mainly limited to a few countries due to economic constraints and processing complexity, so very high resolution LiDAR data is difficult to access. Therefore, collecting small scale objects in complex terrain with low and medium resolution LiDAR data is difficult.

As the cost of collecting LiDAR data gradually declined, LiDAR data became more affordable to users, but how to effectively process raw LiDAR data and extract useful information remains an important challenge. Oversampling is unavoidable in most cases because there is no way to match the data acquisition density by terrain type during a LiDAR data acquisition operation. As a result, a key challenge when using LiDAR data is the amount of data stored and the computational requirements required processing such high density datasets. Moreover, due to the unique characteristics of LiDAR data, issues such as modeling method selection, interpolation algorithms, grid size, and data reduction make it difficult to study topics for generating high quality DEMs from LiDAR data.

CONCLUSION

Floods have devastating consequences in terms of displacement, loss of life and damage to infrastructure and property. One measure to reduce losses is early warning of risks through flood maps. Flood maps and models showing the magnitude of the projected floods for this extreme event are widely used in all types of spatial planning and serve as information materials for the population. It is very important for policymakers to take timely decisions on emergency response and future planning. These maps not only identify future flood prone areas, but also provide valuable information to rescue and rescue services, land planners and local authorities. In flood modelling and monitoring, detailed topography information (CMR) is an important input that can be obtained from various earth observation satellites.

While LiDAR data have become more accessible to users, as the costs of collecting LiDAR data are gradually decreasing, the efficient processing of LiDAR raw data and the recovery of useful information remains a major problem. It is not possible to compare the density of data collection with the type of area during the LiDAR data collection operation, so some prioritization is almost always inevitable. As a result, the large amount of data stored and the time needed to complete the calculations required to process such dense data sets is an important problem in the use of the LiDAR data. In addition, because of the unique characteristics of the LiDAR data, it is difficult to explore such issues as the choice of modelling method, interpolation algorithm, and grid size and data reduction to create a high quality LIDAR CMR.

Thus, the integration of various LiDAR platforms with microwaves such as RADAR and other remote sensing optical products appears to be a promising approach to solve problems associated with inadequate representation of topographic data in complex topographical regions. More importantly, extensive research is needed to improve the filtering (classification) of LiDAR data processing and DEM generation algorithm in heterogeneous landscapes, especially in complex urban areas. Therefore, further research and research work can be expected to develop LiDAR systems into upcoming flood detection and mapping applications.

ETHICS DECLARATION

We hereby declare that this study is our original work and has not been published in any other journals, and all sources of material used for this study have been duly acknowledged. We would like to confirm that we have consented to publish this article at environmental monitoring and assessment.

CONFLICTS OF INTEREST

We declare that no conflict of interest. The funder has no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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