Unmanned Aerial Vehicle Mapping of River Flow for Water Resources Management

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Abstract. Unmanned aerial vehicle surveying of the riverbed enables detailed mapping of the river flow, which is useful for various purposes such as flood management, ecosystem monitoring and geological processes. Unmanned aerial vehicles are used to collect data on water height, flow velocity and bed shape, creating precise maps of river systems. This process can be fast, efficient and safe for operators, and is therefore increasingly used in scientific research and water resource management.

Riverbed surveying can be done with a LiDAR (Light Detection and Ranging/Laser scanning) camera which collects visual data on the condition of the riverbed, such as changes in shape, erosion and sedimentation. LiDAR cameras, also known as side-scan sonar, use sound signals to collect data on the depth and shape of the riverbed and create a precise 3D map of the riverbed. This process enables a detailed analysis of the river system and is useful for water resource management and environmental protection.

The paper will give an overview of the methods and technologies that are currently relevant for the implementation of such recordings. Also, future work will be presented, as well as the advantages and challenges of such a project from an economic and technological point of view.

Keywords: River flow mapping · Unmanned aerial vehicles · Water resource management

1 Introduction

River flow mapping is the process of quantifying and visualizing the movement of water within a river. In order to create an accurate representation of how water moves through a river channel, effort in measuring various parameters related to water flow, such as velocity, discharge, and depth need to be made.

There are several methods and technologies used for river flow mapping, like current meters. These are mechanical devices deployed in the river that measure water velocity at specific points. They typically consist of a rotor or propeller that spins as water flows past, providing information about the speed and direction of the current.

Acoustic Doppler Current Profilers (ADCP) use sound waves to measure water velocity across multiple points in the river column. By analyzing the Doppler shift in the frequency of sound waves reflected off particles in the water, ADCPs can determine the speed and direction of the flow at different depths.

Stream gauging involves a combination of measurements, including water level and cross-sectional area, to calculate river discharge. Discharge is the volume of water passing through a particular cross-section of the river per unit of time and is a critical parameter for understanding river flow.

Remote sensing technologies, such as images obtained from satellite or unmanned aerial vehicles (UAVs) photography, can provide valuable information for river flow mapping. For example, analyzing changes in water color or patterns on the surface can indicate variations in flow velocity and direction but also give information about surroundings.

Advancements in technology, such as unmanned aerial vehicles equipped with cameras or LiDAR (Light Detection and Ranging) systems, have made it easier to capture high-resolution data for river flow mapping. These tools can provide detailed information about river morphology, including the shape of the river channel, bedforms, and sediment transport.

The data obtained from river flow mapping is crucial for various applications, including hydraulic engineering, flood management, water resource planning, and environmental monitoring. By understanding how water moves within a river, scientists and engineers can make informed decisions regarding infrastructure development, river restoration, and the protection of aquatic ecosystems. These technologies offer high-resolution data collection capabilities, allowing for detailed and accurate mapping of river channels and hydrological features.

In this article, economic and legal aspects related to river flow mapping will be given in Sect. 2. In Sect. 3, LiDAR system overview is given with its specifications and image examples following by last chapter where all is concluded.

1.1 LiDAR Cameras in River Flow Mapping

Unmanned aerial vehicles (UAVs) equipped with cameras or LiDAR have been extensively used in various research areas related to river systems and hydrology. Some notable applications include river morphology and channel changes, where UAVs with LiDAR cameras can provide high-resolution data for studying river morphology, including changes in river channels over time. Researchers can analyze elevation models, digital surface models, and orthophotos to quantify erosion, deposition, and changes in riverbed features.

In [1] they describe a new methodology for creating high-resolution seamless digital terrain models (DTM) of river channels and their floodplains. Flood modeling and risk assessment is highly important for areas near the river with inhabitants. This technology can aid in identifying flood-prone areas, understanding flow patterns, and assessing potential impacts of flooding events.

UAV-based mapping can help estimate sediment transport rates and erosion patterns within river systems. By analyzing high-resolution imagery or LiDAR data, researchers can track changes in sediment deposition, measure erosion volumes, and investigate

the impact of sediment dynamics on river ecosystems. The current revolution in the scientific research related to coastal and littoral hydrosedimentary dynamics, putting into perspective connections between coasts and other geomorphological entities concerned by sediment transport are well synthesized in [2].

As illustrated in [3], recent developments and perspectives for riparian vegetation monitoring purposes are shown through three examples of image sources: Light Detection And Ranging (LiDAR), radar and Unmanned Aerial Vehicle (UAV) images. LiDAR sensors are valuable for monitoring vegetation dynamics along river corridors. They can assess vegetation density, species composition, and changes over time, providing insights into the ecological health and functioning of riparian ecosystems.

UAVs play a crucial role in river restoration projects by providing detailed baseline data and monitoring the effectiveness of restoration efforts. They can capture data on pre- and post-restoration conditions, allowing for the evaluation of habitat restoration, fish passage improvements, and vegetation management. UAVs, ground surveys, and satellite imagery were used in [4] to evaluate vegetation metrics for three riparian restoration sites along the Colorado River in Mexico and they compared the data accuracy and efficiency (cost and time requirements) between three methods.

The problem of searching and mapping river boundaries, bridges and coastlines are addressed in [5]. This paper describes an exploration system that equips a fixed wing UAV to autonomously search a given area for a specified structure such as river or coastal line, identify the structure if present and map the coordinates of the structure based on images from an onboard sensor (could be vision or near infra-red).

As rivers are a major source of plastic waste in the oceans by [6], where they estimated that 1000 rivers are accountable for nearly 80% of global annual riverine plastic emissions, it is quite significant to examine the research presented in [7]. They propose automatic mapping of plastic in rivers using unmanned aerial vehicles (UAVs) and deep learning (DL) models that require modest compute resources. Also, they investigated the performance of pretrained and tabula rasa object detection models for plastic detection using data acquired from a Mekong river tributary, the Houay Mak Hiao (HMH) river in Vientiane, Laos, as well as a canal in the Bangkok area, Khlong Nueng in Talad Thai (TT), Khlong Luang, Pathum Thani, Thailand. Further exploration on how a model trained on one location performs in a different location in terms of compute resources, accuracy, and time is made.

Overall, the use of UAVs equipped with cameras or LiDAR has revolutionized research in river systems, enabling more detailed and accurate data collection, monitoring, and analysis.

2   Economic and Legal Aspects Related to River Flow Mapping

Free-flowing rivers influence the diversity and dynamism of ecosystems on a global level. They are the source of a healthy environment and human well-being. Also, they have a significant social and economic role. Human influence through infrastructure development in an attempt to secure economic prosperity is affecting the number of such rivers and thus biodiversity and security. As indicated in [8], by 2050, the lives of 2 billion people living in flood-prone areas will be affected by climate change, population growth, deforestation, and rising river and sea levels.

According to [9], only 37% of the world's rivers longer than 1,000 km still have a free flow along their entire length, and post-natural hydrologic flow will change for 93% of the river volume by 2030. This has implications for the challenges associated with the services that rivers provide from an economic perspective. For example, providing drinking water to households, developing agriculture, supporting power generation, industrial production, and providing transportation links. Very few rivers in densely populated areas flow freely because of the need to build dams, impound water, and align the river. As a result, river connectivity can be lost, which can have various disastrous consequences such as flooding, but also economic consequences such as the disruption of navigable transport routes, which are still the cheapest form of transporting goods. According to [10], river floods are a common phenomenon worldwide with catastrophic long-term consequences for humans and the environment. They entail high monetary losses, but are often irreparable. Therefore, the identification of possible flood areas is extremely important, and although they require significant material investments, they ultimately pay off. As stated in [11], it is also important to take care of environmental protection and to timely detect changes related to soil erosion and sedimentation, which are often the cause of changes in water flows. Technology can greatly help us in gaining knowledge about the current state of the river system, but also in finding optimal solutions related to the impact of future changes in water resources for the benefit of humanity.

According to [12], the continuous collection and processing of data to monitor ecosystems, geological processes, the height and velocity of water flow in riverbeds, and the shape of the riverbed can significantly reduce the risks of flooding, which have significant negative consequences for human life, health, and property, the environment, cultural heritage, and economic activity. It is necessary to take care of the process of surveying the trough in order to make it fast, efficient and safe for the operators. According to [13], the absence of the above points can significantly affect the higher cost of carrying out certain activities and the cost of necessary remediation of the consequences of unfortunate events during the implementation of activities. In the Republic of Croatia, the legal aspect of water management is governed by the Water Act, NN no. 66/19, 85/21 and 47/23 [14–16]. It is based on the legal acts of the European Union and regulates the legal status of water, water resources and water structures, special activities for the needs of water management, institutional structure for the implementation of these activities and other issues related to water and water resources. There is a wide range of concepts related to water resources and their natural characteristics, and in this sense, they require a different approach to their monitoring and management. For example, a river is a terrestrial body of water that flows mostly on the earth's surface, but may also flow partially underground. A river basin is an area where all surface water flows through a series of streams, rivers, and possibly lakes, and through an estuary. Some rivers discharge to the sea through estuaries or deltas and have associated groundwater and coastal waters. Due to the varying geomorphological structure of the land in the area, there are different approaches to the banks of the rivers, raising the question of the safety and effectiveness of monitoring the status of water resources. The use of technology brings many benefits as well as risks in its use. Therefore, there are many

European Union legal regulations that provide its members with uniform guidelines for conducting water resource collection activities.

Examples of this are:

1. Regulation (EU) 2018/1139 establishing common rules in the field of civil aviation and creating the European Aviation Safety Agency (EASA), which provides a framework for the safety and management of civil aviation in the European Union; the EASA agency is responsible for developing technical standards and certifying aircraft [17].
2. Directive 2014/89/EU establishing a framework for spatial planning in the maritime area, which, while referring to spatial planning in the maritime area, also provides guidance for spatial planning of other water resources, including rivers, and helps to coordinate activities in areas under the jurisdiction of several Member States [18].
3. Directive 2000/60/ EC establishing a framework for action in the field of water policy, which establishes a framework for the protection and management of water resources, including rivers. It covers aspects of water quality, water quantity, monitoring and planning [19]
4. Regulation (EU) 2016/679 on the protection of individuals with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation - GDPR), which is relevant to the collection and processing of data when using drones for mapping purposes [20].
5. Regulation on aerial photography (Official Gazette 28/19) on the conditions for issuing permits for aerial photography of the territory of the Republic of Croatia carried out by legal and natural persons registered for the activity of aerial photography, and on the conditions for issuing permits for the reproduction, publication and presentation of aerial photographs from the Republic of Croatia, as well as on the procedure for reviewing aerial photographs before their use [21]

In addition, there are other national legal frameworks for individual members of the European Union. For example, in the Republic of Croatia there are:

1. Rulebook for the use of unmanned aircraft in the airspace of the Republic of Croatia [22]
2. Rulebook on the safety and suitability management system of unmanned aircraft operators [23]
3. Rulebook for unmanned aircraft systems [24]

According to [25], legal entities and natural persons may conduct aerial photography of waters in the Republic of Croatia only with a permit. The application is submitted to the State Geodetic Administration and contains information about the person who commissioned the survey, information about the person performing the survey and proof that he/she is performing a registered aerial survey activity, information about the time of the survey, the purpose of the survey, information about the survey area, technical data about the aircraft, the method of scale recording for storing the original data, etc. As stated in [26], the ways to control the use of unmanned aerial vehicles are becoming more complex due to constant changes in the law, which is a result of the increasingly sophisticated technology and the diversity of its application in aviation, which requires greater attention in terms of maintaining safety and protecting property and people. The

consequences of non-compliance with legal requirements can result in significant costs for the contractor of the water mapping, so it is important to have a transparent view of everything to worry about before the actual recording.

3   LiDAR (Light Detection and Ranging) System

LiDAR is an acronym for Light Detection and Ranging, encompassing a remote sensing technology that employs laser light to gauge distances and produce intricately accurate 3D depictions of the surroundings. A LiDAR system normally has a laser scanner, a sensor to detect the reflected laser light, and a positioning system for georeferencing the acquired data. A LiDAR camera, also known as a LiDAR imaging system or LiDAR sensor, integrates LiDAR technology with a camera to capture both 3D point cloud data and high-resolution imagery simultaneously. LiDAR cameras have become increasingly popular in the past few years due to their ability to capture both 3D point cloud data and high-resolution imagery. They offer valuable insights for a wide range of applications and have proven to be essential tools for many industries that require accurate spatial information and visual representation of the environment.

If we look closely at some of the main characteristics of LiDAR cameras, it is important to mention high-resolution imagery. LiDAR cameras are often combined with traditional RGB cameras to capture high-resolution imagery simultaneously with the 3D point cloud data. This allows for the fusion of visual information with the geometric data, providing a comprehensive representation of the scene.

The laser pulses emitted by LiDAR cameras generate a dense collection of 3D points, also known as a point cloud. Each point in the point cloud represents a precise location in 3D space and is associated with intensity information.

The important question that can be risen is when to choose LiDAR cameras and when to use photogrammetry. Photogrammetry is a technique that involves extracting three-dimensional (3D) information about objects or environments from two-dimensional (2D) images. Photogrammetry and LIDAR are quite different from each other, even if their three-dimensional (3D) outputs look similar. While both methods capture locations, photogrammetry requires less expertise to post process and provides photo-realistic results [27]. Photogrammetry can be influenced by factors such as lighting conditions, image quality, and the presence of occlusions. It can provide detailed visual information, while LiDAR excels in accurately capturing elevation data and penetrating vegetation. In practice, a combination of both techniques may be employed to leverage their respective strengths and generate comprehensive data for river flow analysis and modeling.

3.1   LiDAR-Derived Data Used for River Flow Mapping

LiDAR-derived data will be shown on DJI Zenmuse L1 camera. The Zenmuse L1 integrates a Livox Lidar module, a high-accuracy IMU, and a camera with a 1-inch CMOS on a 3-axis stabilized gimbal. When used with Matrice 300 RTK and DJI Terra, the L1 forms a complete solution that gives you real-time 3D data throughout the day, efficiently capturing the details of complex structures and delivering highly accurate reconstructed models [27]. Table 1 gives a detailed specification for DJI Zenmuse L1.

Table 1. DJI Zenmuse L1 specifications

General	Dimension	152 × 110 × 169 mm
	Weight	930 ± 10 g
	Supported Aircraft	Matrice 300 RTK
	Operating Temperature Range	−20° to 50 °C 0° to 50 °C (when using RGB mapping camera)
System Performance	Detection Range	450 m @ 80% reflectivity, 0 klx; 190 m @ 10% reflectivity, 100 klx
	Point Rate	Single return: max. 240,000 pts/s; Multiple return: max. 480,000 pts/s
	System Accuracy (RMS 1σ)	Horizontal: 10 cm @ 50 m; Vertical: 5 cm @ 50 m
	Real-time Point Cloud Coloring Modes	Reflectivity, Height, Distance, RGB
LiDAR	Ranging Accuracy (RMS 1σ)	3 cm @ 100 m
	Maximum Returns Supported	3
	Scan Modes	Non-repetitive scanning pattern, Repetitive scanning pattern
	FOV	Non-repetitive scanning pattern: 70.4° (horizontal) × 77.2° (vertical); Repetitive scanning pattern: 70.4° (horizontal) × 4.5° (vertical)
	Laser Safety	Class 1 (IEC 60825-1:2014) (Eye Safety)
RGB Mapping Camera	Sensor Size	1 inch
	Effective Pixels	20 MP
	Photo Size	5472 × 3078 (16:9); 4864 × 3648 (4:3); 5472 × 3648 (3:2)
	Focal Length	8.8 mm/24 mm (Equivalent)
	Shutter Speed	Mechanical Shutter Speed: 1/2000 - 8 s Electronic Shutter Speed: 1/8000 - 8 s
	ISO	Video: 100–3200 (Auto), 100–6400 (Manual) Photo: 100–3200 (Auto), 100–12800 (Manual)
	Aperture Range	f/2.8 - f/11
	Photo Format	JPEG
	Video Format	MOV, MP4
	Video Resolution	H.264, 4K: 3840 × 2160 30p

There is example of image taken by LiDAR camera DJI Zenmuse L1 and UAV DJI Matrice 300 RTK [29]. AIR-RMLD d.o.o. intension of this flight was to scan the riverbed of river Kupa with its surroundings in the area of Ozalj, approximately the size of 20 000 m^2 (see Fig. 1). The scan was done on 70m height with 300 000 dot/m and precision of 2.5 cm, triple reflection.
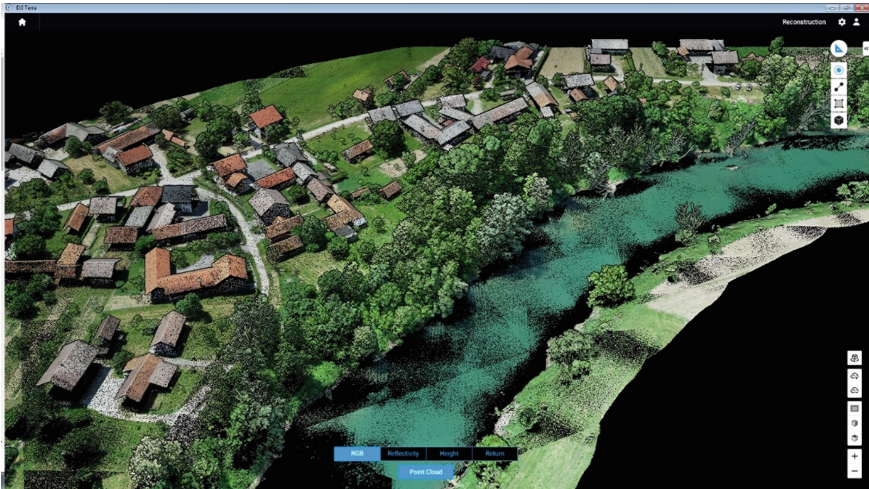
Fig. 1. Scan of the riverbed of river Kupa near Ozalj with DJI Zenmuse L1 and Matrice 300 RTK

Digital Elevation Models (DEMs) provide precise information about the topography, which depict the elevation of the river channel and its surroundings. A review that aims to study the potential and the applications of LiDAR-derived DEM in flood studies is given in [30]. It also provides insight into the operating principles of different LiDAR systems, system components, and advantages and disadvantages of each system.

Water velocity and discharge play a crucial role in monitoring water resources sustainably. In areas that are challenging to access, datasets obtained from Unoccupied Aerial Systems (UAS) provide a viable solution for high-resolution and timely river monitoring. Image or video-based methods have gained popularity in river flow monitoring due to their efficiency and cost-effectiveness compared to traditional approaches. Proposed technologies, i.e., UAV and LiDAR camera combined, give an alternative method for data acquisition that is less time-consuming and more affordable, allowing for effective river monitoring and management. Study [31] presents a non-contact methodology to estimate streamflow based on data collected from UAS. Both surface velocity and river geometry are measured directly in field conditions via the Unoccupied Aerial Systems (UAS) while streamflow is estimated with a new technique.

Bathymetry is the measurement of the depth of water in oceans, rivers, or lakes. Bathymetric maps look a lot like topographic maps, which use lines to show the shape and elevation of land features [32]. Bathymetric mapping is particularly useful for assessing channel morphology, understanding sediment transport, and identifying areas of erosion or deposition. In [33] they evaluate the potential to retrieve water depth of shallow river from high resolution hyperspectral images using an empirical model, applicable under a range of specific field conditions and in a definite interval of wavelengths. Bathymetric data, which includes information about the depths and shapes of underwater terrain, has a range of uses like nautical chart which give accurate information to captains about the depth of the water and potential underwater hazards [34].

4   Conclusion

Water is not a commodity like other products, but a heritage that should be preserved, protected and used wisely. Water is managed according to the principle of unity of the water system and the principle of sustainable development, which meets the needs of the present generation and does not compromise the rights and opportunities of future generations to achieve this for themselves. It is necessary to constantly monitor water resources in order to avoid sudden unfavorable situations related to changes in the flow of the river, the riverbed, etc. It is necessary to constantly search for more efficient, reliable, faster and cheaper methods of recording and mapping in order to make timely decisions on any human intervention that may be necessary.

The primary objective is to exploit the maximum value of river stretches in an economic sense, but also in terms of preserving natural resources for future generations. By combination of UAVs and LiDAR cameras, fast and precise data can be obtained for further analysis of river flow as well as its surroundings. Unmanned aerial vehicles equipped with LiDAR systems have become state-of-the-art tools for river flow mapping giving us opportunity to act promptly to prevent unfavorable situations.

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