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Analysis of flood modeling through innovative geomatic methods

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S U M M A R Y

A suitable assessment and management of the exposure level to natural flood risks necessarily requires an exhaustive knowledge of the terrain. This study, primarily aimed to evaluate flood risk, firstly assesses the suitability of an innovative technique, called Reduced Cost Aerial Precision Photogrammetry (RC-APP), based on a motorized technology ultra-light aircraft ULM (Ultra-Light Motor), together with the hybridization of reduced costs sensors, for the acquisition of geospatial information. Consequently, this research generates the RC-APP technique which is found to be a more accurate–precise, economical and less time consuming geomatic product. This technique is applied in river engineering for the geometric modeling and risk assessment to floods. Through the application of RC-APP, a high spatial resolution image (orthophoto of 2.5 cm), and a Digital Elevation Model (DEM) of 0.10 m mesh size and high density points (about 100 points/m^2), with altimetric accuracy of -0.02 ± 0.03 m have been obtained. These products have provided a detailed knowledge of the terrain, afterward used for the hydraulic simulation which has allowed a better definition of the inundated area, with important implications for flood risk assessment and management. In this sense, it should be noted that the achieved spatial resolution of DEM is 0.10 m which is especially interesting and useful in hydraulic simulations through 2D software. According to the results, the developed methodology and technology allows for a more accurate riverbed representation, compared with other traditional techniques such as Light Detection and Ranging (LiDAR), with a Root-Mean-Square Error (RMSE ± 0.50 m). This comparison has revealed that RC-APP has one lower magnitude order of error than the LiDAR method. Consequently, this technique arises as an efficient and appropriate tool, especially in areas with high exposure to risk of flooding. In hydraulic terms, the degree of detail achieved in the 3D model, has allowed reaching a significant increase in the knowledge of hydraulic variables in natural waterways.

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1. Introduction

The availability of surface water in terms of quality, reliability and safety to people, properties and dependent productive activities, is crucial to any society. There is some consensus in the scientific community that achieving this is only possible through a sustainable resource use within an integrated exploitation framework. This is the international paradigm of performance and analysis of water studies, known as "Integrated Water Resources Management" (IWRM) (Molina et al., 2013).

The reality of climate change, expressed in terms of occurrence of extreme hydrological events, produces a stronger pressure on water resources systems (Chávez Jiménez, 2012; Molina et al., 2013) and the physical environment (Ashley et al., 2005). Consequences on the terrain are slowly conducting the society to take effective protective and adaptive interventions (EU Directive, 2007; Zechner et al., 2011). Most of these interactions are being currently studied in research through non-structural actions (Escuder-Bueno et al., 2012). For that, the decision making on water resources management should include economic considerations, involving the search for a maximum efficiency in the analysis and design of solutions (Sayers et al., 2002). Given this situation, it becomes necessary to have a set of efficient and flexible tools, techniques and methodologies, to facilitate the process of decision making and solutions design.

For a correct assessment of exposure level to natural flood risks is crucial obtaining a detailed-accurate reconstruction of the terrain susceptible to be affected, which provides a proper inundation modeling. In Spain, floods are a natural disaster causing considerable damage, estimated to total about 800 million Euros per year (0.08% of GDP). According to the Consortium of secured property, in the period 1971–2012, 42.9% of the cases processed were due to flood damage, which have accounted for 60.3% of total compensation (MAGRAMA, 2014).

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Nowadays, data acquisition and generation of accurate and reliable geomatic products, in the field of fluvial hydraulics and hydrodynamics, was carried out with costly instrumentation, equipment and platforms (Bates et al., 2003; Garcia-Pintado et al., 2013; Horritt and Bates, 2001; Tsubaki and Fujita, 2010; Turner et al., 2013), requiring highly specialized work teams, with very rigid technical constraints that prolong the process of decision making.

Having data in a quick and accurate way is usually associated with a higher cost. On the contrary, lower cost is usually accompanied by low accuracy and less reliable representation of the terrain, which is directly transmitted to the analysis/risk assessment (Merwade et al., 2008b), and design solutions, with their subsequent economic implications.

However, the new paradigms of geomatic science, result of the progress achieved in the last three decades, provide the scientific and engineering community of a set of reduced cost and even low cost techniques and methodologies. This, directly impacts on more efficient use of economic resources affecting at public administrations and private corporations.

Some of the computer advances in geomatic materialize in aerial imagery processing software, characterized by friendly, sequential, and to some extent automated workflows. This enables non-geomatic expert's users, process their own dataset, configured as an efficient alternative, to the highly specialized professional photogrammetric software packages.

This case study is aimed to assess the suitability of hybrid low-cost sensors, embarked in alternative aerial platforms (lightweight, low speed and suitable for manned flight) of ULM type (Ultra-Light Motor). This, together with the innovative image processing software, gives some alternatives ways in the sphere of river engineering, applied to the modeling and analysis of flow and flood risk assessment. This innovative technique is called Reduced Cost Aerial Precision Photogrammetry (RC-APP).

2. State of the art

The modeling of flooding is characterized by the relationship between flow and physical environment. The surface flow is a physical phenomenon that presents a great randomness in frequency and magnitude, which makes it deterministically unpredictable. For a better assessment and prediction, stochastic models in form of probability (probabilistic distributions or functions) are used in rainfall-runoff modeling (Martínez and Salas, 2004; Ng and Panu, 2010) and, they are indirectly also subjects of this research. Since precipitation is practically pure random process, and physical environment also is random itself, this stochasticity is twofold. Furthermore, land uses and modifications of the terrain and vegetation cover are associated to seasonality. On the other hand, the terrain is the physical support or container of hydrological–hydraulic processes, where the hydrological cycle is related to the environment and humans (Andreu, 1993). The manifestation of the basin behavior related to the hydrological cycle is produced as runoff surface, or as flooding, when the carrying capacity of rivers or channels is exceeded, when hydrological extreme events occur or when infrastructure is not correctly designed.

Nowadays, there is a relative consensus among researchers and engineers on the knowledge of the physical and hydraulic surface hydrology principles, which has enabled water resources planning and management (Balairón Pérez, 2002; Biswas and Tortajada, 2003). However, it should not be overlooked that extreme events are becoming more recurrent over time and consequently, they are less anomalous events over the time. This brings serious consequences on water resources systems functioning (Bates et al., 2008; Estrela et al., 2012), surface hydrology (Dawson et al., 2005) and groundwater (Molina et al., 2013), which makes the climatic variables even more unpredictable, generating more uncertainty.

The accuracy in the definition of flooding is an essential factor, in cartographic and globally terms (Merwade et al., 2008b; Wechsler, 2007; Bales and Wagner, 2009; Jung and Merwade, 2012). The influence of the riverbed terrain and how it has been obtained should not be overlooked in the results of hydraulic simulations (Cook and Merwade, 2009). For this reason, the research is focused on the flooding from the perspective of the physical environment.

The variety of geomatic techniques for data acquisition in modeling flow sensors are exposed and detailed intensively in the study (Molina et al., 2014), where also the precision of each is indicated. In this sense, in the last 30 years, there has been a constant revolution consequence of hybridization between techniques and sensors, as an example the developments in LiDAR (Light Detection and Ranging) exposed in (Irish and White, 1998).

This degree of development has originated, in the last decades of the twentieth century, the appearance of Digital Photogrammetry (DP), as a discipline of geomatic science. DP is fully integrated into many scientists and technicians, such as civil engineering, building, energy, risk assessment, robotics, an even medicine. The main reason is that the photographic image can provide complete information about the object being studied, including metric level and having an image (Gonzalez-Aguilera and Gomez-Lahoz, 2008).

Technological advances in remote sensing and geomatic techniques, in the field of hydraulics and river engineering, are focused on the use of different type of images, mentioned as follows. High spatial resolution, Very High Resolution images (VHR imagery) of 5–10 cm spatial resolution (Lejot et al., 2007), LiDAR Digital Elevation Models (DEM), with nominal accuracies from ±0.15 m to ±0.25 m (Lane et al., 2003), classic surveying with accuracy of ±0.05 m (Prinos, 2008), the use of observations Synthetic Aperture Radar (SAR) as a source of calibration flood modeling (Horritt and Bates, 2001), and the use of innovative aerial platforms low flying height, Unmanned Aerial Vehicles (UAV) (Vallet et al., 2011), which allow high spatial resolutions, but have a set of limitations, technical and administrative described in (Hardin and Jensen, 2011; Watts et al., 2010). The temporary flight restriction penalizes its applicability in river studies as it is shown in (Ortega-Terol et al., 2014), with a study case length of 132 km.

In order to generate flood risk maps, the construction of continuous Digital Terrain Model (DTM) is essential. In this case, it is common the integration of geometric data from different sources (Prinos, 2008), such as Topographic and Bathymetric LiDAR, classic surveying, with different accuracies (Molina et al., 2014), and the combination of these, through grids (Raster/GRID) and Triangular Irregular Network (TIN) (Merwade et al., 2008b).

On the other hand, Geographic Information Systems (GIS) as a procedural and integrated tool, applied as a physical terrain support for modeling flows are fully seated in the scientific and engineering community, as seen in (Chen et al., 2009; Liu et al., 2014; Merwade et al., 2008a; Wiles and Levine, 2002). Likewise the combination of geomatic techniques and GIS, in the geometric study of riverbeds can be viewed in works such as (Bates and De Roo, 2000; Marcus and Fonstad, 2008). However, the majority of the work and studies have in common that the acquisition of geometric information is from aerial platforms and/or satellite with onboard sensors, in both cases, high cost (Bates and De Roo, 2000; Legleiter and Overstreet, 2012; Marcus and Fonstad, 2010). For example, an individual high spatial resolution satellite image, up to 0.25 m, could cost around € 7000 (Airbus Defense & Space and Infoterra SGSA, 2015), with a minimum area of 14.8 km^2 (4×3.7 km). This minimum area can be much higher than the one needed for the study case, and it may be possible to require more than one image, due to the specific characteristics of the sensor data acquisition protocol.

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