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The use of laser surveying technologies in 2-D flow simulations: the Tagliamento River case.

L. Falcomer, M. Maso and D. Russo

Flood wave numerical simulations represent a very important tool in flood risk analysis especially for areas next to large rivers. The improvements in computer technology allowed the use of more and more complex and accurate models, such as 2-D models, in application to practical cases. The aim is to simulate the propagation in time and space of a flood wave. For these kind of models it is very important to have a precise geo-morphological description of the topographic surface. The quantity and the quality of available topographical data obtained with the classical methodologies, are often not sufficiently adequate to allow a good representation of the domain geometry. In fact, the description of channels, embankments, bridges, abutments etc..cannot be neglected to obtain an accurate simulation of the flood propagation. In this context, the use of new surveying methodologies such as laser surveying could turn out very useful. This technology, is able to produce on average a measured point per square meter, with a good level of accuracy. Of course, the use of such a large amount of surveyed points in hydrodynamic models would require an unsustainable computational effort. For this reason it is necessary to perform a reduction in the data set by some mathematical algorithm. Once the number of points has been thinned out, it’s possible to select manually additional points, where a more precise description of the geometry is necessary. The analysis of the digital orthophotos of the corresponding areas, usually taken at the same time of the survey, makes the thickening procedure much easier. Moreover, by this analysis, it is possible to assign local values for the Manning coefficient, distinguishing the main channel from the floodplain, by taking into account the vegetation density, and so on. An application to the Tagliamento River (North Eastern Italy) is developed, in order to highlight the capability of this procedure. Particularly, the simulation of a reach, 45 km long and 2 km large, is presented in application to the 1996 flood event, with a peak discharge equal to 4500 m^3/s.

Keywords: Laser surveying, bidimensional, numerical model, Tagliamento River

1 Introduction

The aim of this article is the evaluation of an interaction between data laser surveying technology and two dimensional analysis of river flood. In channel and river engineering, two-dimensional (2D), depth averaged model are beginning to join one-dimensional models in common practice. These models are useful in studies where local details of velocity and depth distribution are important. Examples include bridge design, river training, diversion works, bifurcations, contaminant transport and flooding hazard. As input data, 2D hydrodynamic models require the topography, roughness and eddy viscosity distributions, boundary conditions, and initial flow conditions. In addition, some kind of discrete mesh or grid must be designed to capture the flow variations. Obtaining an accurate representation of bed topography is likely the most critical, difficult, and time consuming aspect of the 2D modelling applications. There are different techniques to carry out the topographic survey; the most simple one is based on cross sections surveying, but generally it lacks of information along the floodplains. A more sophisticated solution, adopted in presence of relevant water levels, is the interaction between the cross section survey, to define the dry areas and depth sounding system in order to define the river bathimetry. Recently, a methodology based on laser surveying became available, which is able to describe land morphology in a complete and accurate way. This technology, infact, allows to have a measured point per square meter on average, with a good level of accuracy. This technique is not applicable in presence of water, where the survey can be completed by other methodologies, such as field surveys or multibeam laser technology.

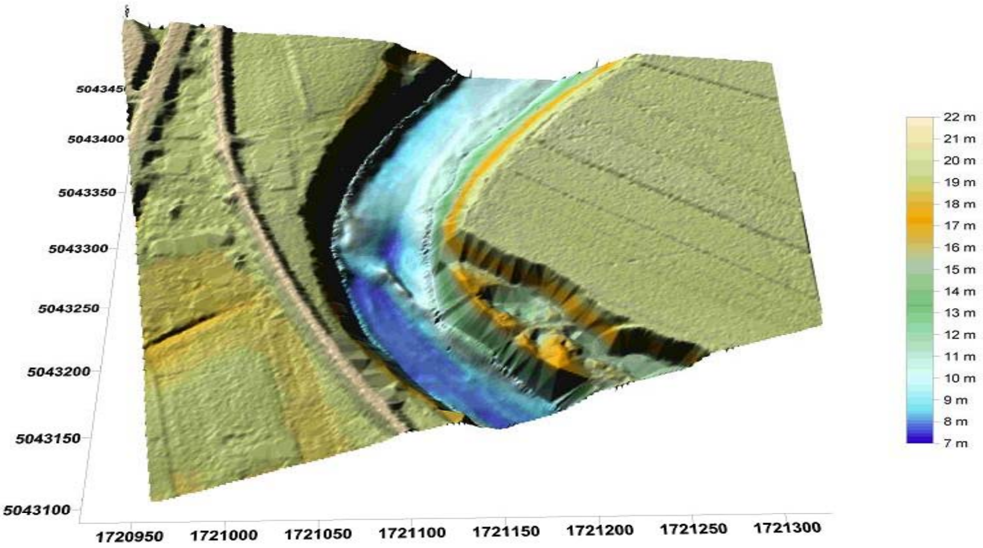

Figure 1: Laser data together with bathymetry

An accurate 2D flow analysis, based on shallow water equations combined with an opportune closure model, doesn't require such a quantity of data as obtained from laser surveying. An opportune analysis of the data is hence necessary to obtain a significant description of the computational domain representing better the relevant terrain features. The data laser selection for the mesh construction may be done by comparison with the orthophotos (usually taken during the survey time), by recognition of the elements, such as islands, levees, bridges, buildings, groynes, etc., relevant for simulations. In this work we will show an application of data laser survey to construct the computational domain in a 2-D simulation of the Tagliamento River (North Eastern Italy) in order to evaluate the velocity field and the water level distribution.

2 Laser survey

A precise knowledge of the geometry of watercourses and their related characteristics is essential to most analyses of river hydrology, ecology and for risk assessment. Therefore, we need an instrument able to correctly describe the land topography, producing a digital terrain model (DTM). The typical products obtained through photogrammetric methodologies describe the earth's surface by either the representation of plane curves or the digital models deriving from them. It is well known, nonetheless, that a photogrammetric generation from the DTM, be it automatic or manual, meets with difficulties when dealing with woods or densely built-on areas. Moreover, a clear view of the ground analized is often thwarted by different causes: perspective occlusions (shadows), inadequate conditions of nadir on large portions of the surveyed area, and a limited stereoscopic performance (each single point has to be visible from two different positions). The laser surveying technique is a particularly useful and competitive method which overcomes, to a great extent, the problems stated above. The surveys, if correctly planned, allow us to obtain a tangible description of the ground and data, characterized by a very high objective precision. This work describes the methodology devised for the acquisition and processing of data and images obtained through aerial surveys of the main branch of the Tagliamento River with an airborne OPTECH ALTM 1210 integrated with a digital camera KODAK DCS 460. In the area of about 180 km^2 from Stretta di Pinzano to the river mouth, a precise and point dense topo-altimetrical survey was taken, and a DTM with its related digital orthophotos (scale 1:5000) was derived. The laser surveying finds its major practical applications in the analysis of the morphological relief and its three-dimensional modelling. Nevertheless, it can be particularly useful in the survey of river cross sections, as well as in defining digital elevation model (DEM) to be used in hydraulic modelling, both numerical and physical.

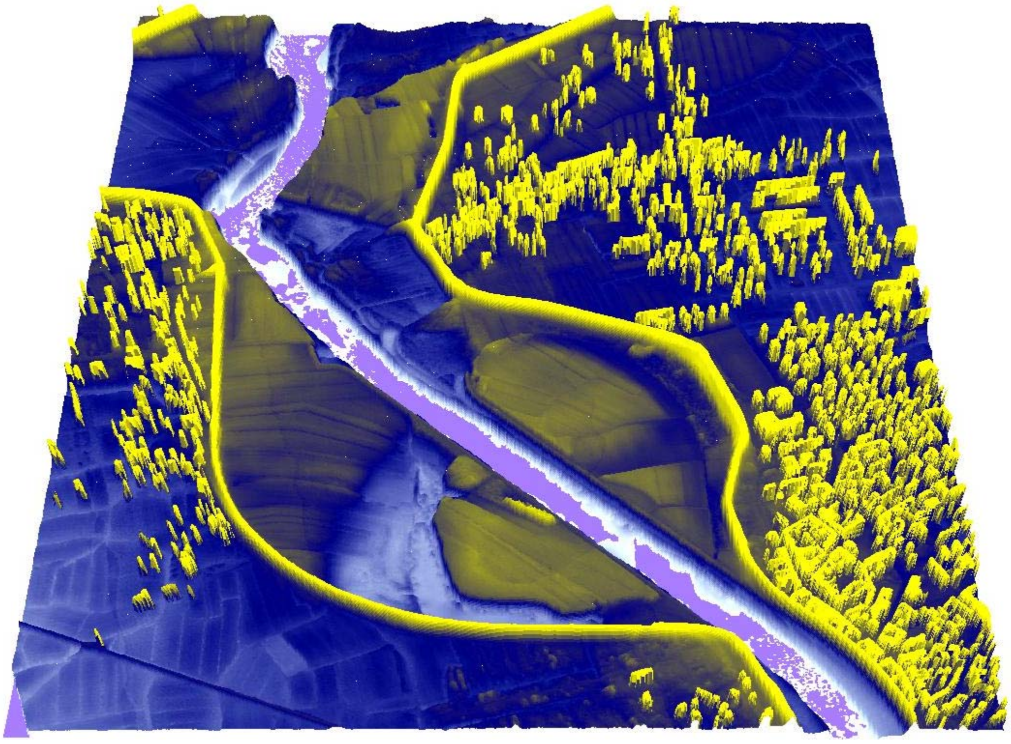

Figure 2: Elaboration data example: 3-D image

Recently, the diffusion of this type of product allowed the development of research which demonstrated its value in several fields of application, as well as its ability to guarantee extremely precise parameters. Unfortunately, specific data processing and post-processing tools are not yet available and this aspect constitutes a major drawback when treating such large amounts of data. For this reason, in this work a methodology to treat data laser for hydraulic purposes has been developed. Moreover, as official quality standards are not available, the Autorità di Bacino (ADB) has taken into account the development of tenders and test regulations, in order to obtain products with tolerance values well beyond both the cartographic and orthophoto reference scales.

2.1 Working principle

The working principle of laser scanning is the surveying of an area by an airborne laser telemeter, which determines the distance from the ground as a function of the time taken by a laser beam to be reflected. The three-dimensional coordinates of the ground are obtained through the interaction of all the sensors making up the laser scanner system. These are:

- A laser telemeter, which measures the distance from the ground to the airplane;
- An inertial system (INS) integrated to the aircraft, which determines the attitude in relation to the degrees of freedom due to rolling, pitching and drift;
- The GPS, which determines the geographical position of the aircraft in relation to the system of reference coordinates.

Figure 3: On-board airplane sensor

The system of on-board sensors is completed by a digital camera, which permits the simultaneous recording of orthophotos. Being created by an active and coherent sensor, the pulse from the laser signal generates a beam which has the same geometric behaviour of a line; the spot that the signal creates on the ground has a diameter between 20 cm and 2 m and is proportional to both the altitude and the angular aperture of the sensor (sensor range). The width of the spot can cause multiple reflections: for example, when a beam strikes the head of a tree, a part of the signal will soon be reflected and the rest will reach the ground and be reflected later. Multiple reflections of the same beam are recorded by a receiver at different times, making it possible to select the category of returning echoes. The accurate control of recording procedures makes the acquisition of data and their processing particularly efficient: if we need to determine the height of vegetation, we will use the first returning pulse; if our objective is the altimetry in woody areas, we will use the last returning pulse, so as to be able to record the highest possible number of reflected points in the ground. The laser telemeter employs signals in the infrared frequency (1047nm), which are reflected, rather than absorbed, by the ground. Although this frequency is reflected by vegetation and clouds, the instrument can operate with meteorological conditions which would make the use of the classical methodology quite hard: it can work any time during the day, all year round. Laser scanning surveys can also be useful to provide an almost real time fact-finding support during emergency situations like floods or landslides.

3 The Tagliamento River case

In this work a 2-D model of a Tagliamento River reach, between the Pinzano river station and the Ronchis river station, is made in order to evaluate the advantages in using laser surveying technology for this kind of applications. The model domain is 45 km long and 2 km large, on average.

Figure 4: Tagliamento River

3.1 Numerical model

The 2-D, depth averaged, mass and momentum conservation equations are:

$$(1)\ \frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=0$$

$$(2)\ \frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial \eta}{\partial x}=\frac{1}{\rho h}\frac{\partial h\tau_{xx}}{\partial x}+\frac{1}{\rho h}\frac{\partial h\tau_{xy}}{\partial x}-\frac{\tau_{bx}}{\rho h}$$

$$(3)\ \frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial \eta}{\partial y}=\frac{1}{\rho h}\frac{\partial h\tau_{yx}}{\partial x}+\frac{1}{\rho h}\frac{\partial h\tau_{yy}}{\partial x}-\frac{\tau_{by}}{\rho h}$$

where h is the depth of flow, u and v are the velocity components in the horizontal x and y coordinate directions, t represents time, g is the gravitational acceleration, η is the water surface elevation, ρ is the water density, τ_{xx} and τ_{yy} are the normal turbulent stresses in the x and y directions, τ_{xy} and τ_{yx} are the lateral turbulent shear stresses, τ_{bx} and τ_{by} are the bed shear stresses in the x and y directions respectively. The bed shear stresses are computed by the following formulas $\tau_{bx}=\rho c_f u|V|$ and $\tau_{by}=\rho c_f v|V|$ where: $|\mathbf{V}|$ is the modulus of the velocity vector, $c_f = gn^2/h^{1/3}$ and n is the Manning's roughness coefficient. The turbulent normal and shear stresses are formulated according to the Boussinesq's assumption as $\tau_{xx}=2\rho\rho_t\frac{\partial u}{\partial x}$, $\tau_{yx}=\tau_{yx}=\rho\nu_t(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x})$ and $\tau_{yy}=2\rho\rho_t\frac{\partial u}{\partial y}$ where ν_t is the depth averaged eddy viscosity. The boundary conditions are the measured discharge at the upstream section and the measured water level at the downstream sections. These conditions are known with reference to their overall value along the boundary sections, as obtained with a punctual observation, and they are very difficult to apply properly in a 2-D scheme that requires the knowledge of their values at every point. For this reason, the stage discharge relationship is not assigned at the boundary, rather it is checked at proper control sections, which are located about 20 times the maximum depth upstream from the outlets of the model, to let the flow conditions adjust freely. The closure of the numerical model (1) needs a choice for the depth averaged eddy viscosity ν_t and the Manning's n coefficient.

3.2 Eddy viscosity effect

The turbulence eddy viscosity is very important to define the velocity field in a 2D simulation. In fact, it influences the loss of turbulent energy at the unresolved scale of turbulence, characterised by a dimension less than the size of the geometric elements used in the mesh discretization. It must be put in evidence that the choice of this parameter is not associated only at physical considerations but is related to the numerical viscosity too. The numerical stability of a 2D dimensional code, increase with eddy viscosity but if it exceeds the flow field it may be not properly simulated and the shear stress it becomes very large and unrealistic; the suggested values, reported in literature, vary between 2.4 and 30 m^2/s^{-1} increasing with the element size and change with flow characteristics, as shown in *Zanichelli et al. (2002)*, *King and Norton (1978)* and *Rodi (1993)*.

3.3 Roughness coefficient effect

Bed roughness, in the form of a roughness height or Manning's n value, is a less critical input parameter. Compared to traditional one-dimensional models, where many two-dimensional effects are abstracted into the resistance factor, the two-dimensional resistance term accounts only for the direct bed shear. The use of these coefficients in 1-D problems is questionable since they take into account in an overall manner channel cross section irregularities, sinuosity and meandering, while, in 2-D models, in the τ_b evaluation, the bottom roughness is mostly accounted for; for this reason, a lesser value in n should be expected. This reduction should be more relevant for the main channel than for floodplains, where velocity is moderate and where the equivalent roughness largely depends on vegetation (its height, density, distribution and type. The roughness coefficient doesn't depend on the mesh dimensions and can be estimated based on physical considerations, within a limited range of variability. Values for the Manning's coefficients are suggested in technical literature for 1-D problems, based on surface roughness, vegetation effects, and water depth as well as on the basis of channel geometry (e.g. *Chow (1959)*).

3.4 The 2-D simulation

In order to evaluate the velocity field and the water levels (especially in the floodplain areas) in the Tagliamento River, a 2-D model has been performed. The geometrical dimensions of the physical domain are, on average, about 45 km long and 2 km large. The mesh used to discretize the computational domain is developed by 7600 data laser points and 14500 triangular elements. The elements size change over a range of 25 to 250 m.

The 2-D simulation was costant in time; a discharge of 4500 m^3s^{-1} was used as upstream boundary condition and a water level of 11.9 m a.m.s.l., as derived out by a given rating curve, was imposed at the downstream boundary condition. The 2-D simulation has been performed using a value of turbulent eddy viscosity equal to 15 m^2s^{-1}, as suggested in literature for this kind of flow and discretization. About the Manning coefficient, an analysis of the river morphology, based on the orthophotos, suggested a value of 0.03 s $m^{-1/3}$ for the bed river and a value of 0.04 s $m^{-1/3}$ for the floodplain areas. The choice of these values has been supported by the comparison with some measured data of velocity and water level obtained with the same discharge condition and not presented in this article.

3.5 Conclusion

In this article the capability of laser survey has been evaluated in order to perform a 2-D numerical simulation of the Tagliamento River. With the use of this methodology it is possible to obtain a fully geomorphological description of the computational domain. The large amount of points being surveyed (a data point per square meter) would require, of course, an unsustainable computational effort. For this reason, thinning procedures were necessary in order to have a reasonable number of data points. The availability of such a great number of data points has permitted, anyway, a realistic refinement of particular zones of the computational domain. The methodology here presented proved accurate when comparing the simulation results with direct measurements at same gauging stations along the Tagliamento River.

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