Hydrographic Surveying of Small Alpine Rivers

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Key words: hydrographic surveying, RTK-GPS, TPS, echo sounder, hydraulic modeling

SUMMARY

The implementation of the EU Water Framework Directive as well as flood protection initiatives require to monitor alluvial plains and the riverbeds morphology not only for large rivers but also for tributaries. In the case of the riverbed monitoring of small rivers, state of the art hydrographic surveying systems, which are used for bathymetry in bays or large rivers, cannot be applied due to the specific topography of small rivers. Narrow stream courses and steep embankments on the one hand and river banks abundantly covered with vegetation on the other hand impedes the use of heavy survey vessels. For instance, accurate real time kinematic (RTK)-GPS positioning is often not guaranteed due to signal disturbance caused by heavy tree canopy or even obstruction of the signal because of the surrounding topography.

In this paper a modular hydrographic surveying system for tributary rivers is presented. It is a modular system, which can be easily mounted on almost any boat. The central components of this system are a hybrid positioning unit, a single-beam echo-sounder and a rugged mobile computer. The high accuracy hybrid positioning unit consists of a RTKGPS system and a motorized total station with automatic target recognition (TPS). The primary data source for positioning purposes is the RTKGPS solution (centimeter accuracy). In the case of GPS signal loss the TPS system is set up at the river bench and takes over the positioning of the measuring platform by tracking the 360° circular prism mounted on the boat automatically. The resulting position is transmitted to the main computer on the boat via radio link every 0.2s. All sensors of this hydrographical surveying system are synchronized by GPS PPS timestamps and the measurements are stored in a central hydrographical data base. Positions as well as depths are visualized on chart plotters onboard the boat in real time. Thus missing data or measurements of bad quality can be detected immediately, which avoids costly error handling and reduces the post-processing needs.

Another advantage of the system is the collateral use of the TPS system. It can be applied for surveying the riverside, while it is not needed for positioning the survey vessel.

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1. INTRODUCTION

The standards for the required quality and number of hydraulic simulations have risen since the EU Water Directive came into effect in 2003. These requirements are valid not only for large rivers, but are also becoming more and more important for small- and medium-sized rivers.

Additionally, in order to control the success of these concepts after implementation in the field, a monitoring program of several years will be imperative. Through applying the appropriate monitoring concept, we can verify to what extent the results of the simulation work when applied in reality. The knowledge we receive from this comparison will help to improve the current simulation model.

Successful numeric flow modeling in the future will be based on using a simulation of a dynamic river bed. Of special interest are changes in morphology, and the impact of this on high water protection measures and the ecology of the surrounding river area.

To get sufficient accuracy for calibrating these models, we have at the moment insufficient information about changes in the river beds of small- and medium-sized rivers.

For these purposes the topographical and morphological situation of the riverbed and its adjacent alluvial plains will be described usually by Digital Terrain Models (DTMs). The applied hydraulic 2D/3D-models require DTMs of river zones with a very high density of measurement points, accurate within a few centimeters and an appropriate arrangement of the DTM grid points (Fig.1).

In order to obtain suitable data for this purpose, it requires an adequate hydrographical surveying method.

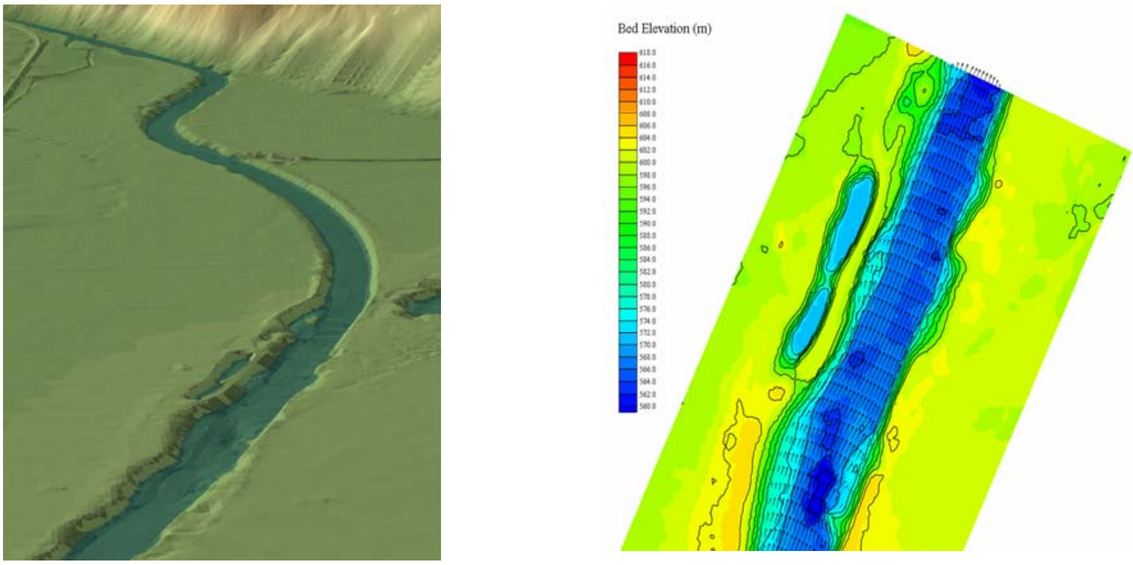

Fig 1: Shaded DTM of river Drau and the result of an applied hydraulic model

2. POSITIONING OF ECHO SOUNDING: REQUIREMENTS AND STATE OF THE ART

As opposed to land, the river bed undergoes many changes due to the impact of high water occurrences and different currents. Therefore, frequent repeated measurements have to be taken to define the actual shape of the river bed geometry, and to be able to determine changes in it. It is imperative to be able to measure the height with high accuracy, because in general the height of the river bed changes only a few centimeters per year. The tendencies of alluvial deposit and river bed erosion are critical to sustainable planning, and therefore have to be determined very precisely.

2.1 Multi-sensor Positioning Systems on Surveying Vessels

The development of the field of kinematic trajectory determination using multi-sensor systems led a few years ago to the application of Real-Time-Kinematic-GPS (RTKGPS) for hydrographic surveying of large river beds. The integration of further systems, such as the electronic compass, electronic inclination sensors, gyroscope, and acceleration sensors ("Inertial Navigation Systems" INS), allows for the determination of the trajectory accurate to within a few centimeters, even in areas with bad GPS signal quality.
This type of surveying vessel fulfils the requirement of accurate hydrographic surveying, but their application is reduced to bays, harbors, or wide rivers, due to their large displacement. An efficient use of these vessels is not possible for small- and medium-sized rivers, for the following reasons:

- Low depth of water, and wide range of fluctuation in depth during the day.

- Narrow width, with many stone obstacles requiring boats to maneuver within strict limitations at low speed (at times stopping and reversing). These maneuvers are anathema to the characteristics of INS systems. Until now, no existing practical investigations have been undertaken to determine the efficiency of using the INS systems on such small measuring platforms. The mobility characteristic of a surveying vessel with heavy tonnage is fundamentally different to that of a small boat on a medium-sized river.

- From an economic point of view, an important factor not to be ignored is that the INS platform costs in the range of hundreds of thousands of Euro.

2.2 Single-sensor Positioning Systems

2.2.1 Trajectory Measurement using Stand-alone TPS and GPS

RTKGPS systems as well as modern motorized theodolites with target recognition systems ("Terrestrial Positioning System" TPS) enable many new applications in hydrographic surveying. Using this GPS-Satellite based technology or TPS, the trajectory of any measuring platform (Boat etc) can be automatically determined in real time. In this case, the trajectory is not continuous but can be made up of discrete single measurements with a frequency of 5 Hz for the TPS and 20 Hz for the GPS. In the case of river bed measurements, this means with a standard boat velocity of 1 m/s, the position of the boat is calculated every 20cm with TPS, and with the GPS system every 5cm.
The accuracy of the 3D-positioning in a kinematic measurement mode using the new generation of instruments is within several centimeters in a controlled situation. In a practical application, the resulting accuracy of both instrument types depends very much on the work environment.

2.2.2 Limitations and Requirements

In the last two years, studies conducted on small- and medium-sized rivers have showed that a single application of TPS for locating the echo sounder is very cost-intensive and in many cases inefficient. For instance, very high and dense vegetation on the river bank requires the placement of many TPS sensor positions. This movement from one TPS sensor position to the next is time-consuming, and leaves a costly boat crew under-utilized. Therefore, RTKGPS systems mounted on the boat are a common alternative. For example, for highly accurate hydrographic surveying, such as monitoring the geometry of storage lake beds, GPS does not provide the required accuracy of 3cm in height. To guarantee efficient and highly accurate surveying for these purposes, it is therefore necessary to combine the GPS system with other sensors.

The topography of small- and medium-sized rivers is composed of steep banks and high and dense vegetation, which often overhangs the water surface (Fig. 2). This affects the ability of GPS to determine accurate position. Due to reduced access to open sky, the distribution of satellites from which signals are received is limited, and some of the signals are of poor quality. In this case, the calculation of a RTKGPS position is impossible. Only a carrier-phase based DGPS position can be calculated with an accuracy of only ½ meter. In some parts of the river, signals of less than four satellites are available, which means GPS is not a practical positioning system in these areas (Fig.3).

Fig.2: Topography of the alpine river Drau

Fig.3: Scheme of a typical profile measuring operation

Experiences from former projects showed us that even on small-sized rivers, RTKGPS positioning is successful between 60 and 80% of the time. The main difficulty is that we cannot predetermine efficiently if RTKGPS positioning will work or not. On the one hand, the density and spread of tree canopy covering cannot be ascertained in advance; on the other, we cannot predict the distribution of satellites from which we will obtain signals. This means that the possibility of successful RTKGPS positioning is dependent not only on the topography but also on the time of day that measurements are taken.

Thus, there remain just 15 to 40% of dead areas, or “White Patches”, where no GPS positioning is possible. The exact number and location of these areas will only be discovered once you are in the field.

3. NAVIGATION USING COUPLED GPS/TPS POSITIONING SYSTEMS

The goal of this research is the development of a modular hydrographical surveying system for tributary rivers. The central components of the system are the Hybrid Positioning Unit, the single beam echo sounder, and a rugged mobile computer. This system enables the collection of different abiotic parameters of small- and medium-sized rivers in one go in the field.

System characteristics:

- Complete System (Ability to collect different parameters in one go)
- Modular (Applicable to different water-related problems)
- High accuracy and integrity of measurements

- Short measurement time and short post processing time required
- Low staff level needed
- Mobile (useable on different boats, and independent of weather conditions)

The coupling of GPS and TPS is achieved by combining RTKGPS and target recognition motorized tachymeters. Referring to the term “dead reckoning”, or coupled navigation, in this case, when we experience a loss of signal using GPS, TPS bridges the gap. When it is necessary to measure a river bed with higher accuracy, these two components are used paired (see section 2.3.3: Project Salzach). This requires highly precise synchronization of the timing of the two systems. For this, GPS time is used for reference.

3.1 Measuring System

The configuration is established in such a way that RTKGPS is the primary system. In the case of RTKGPS positioning failure (due to bad satellite signal quality, too few satellite signals available, bad satellite geometry) the trajectory segment is determined with TPS (Fig.4).

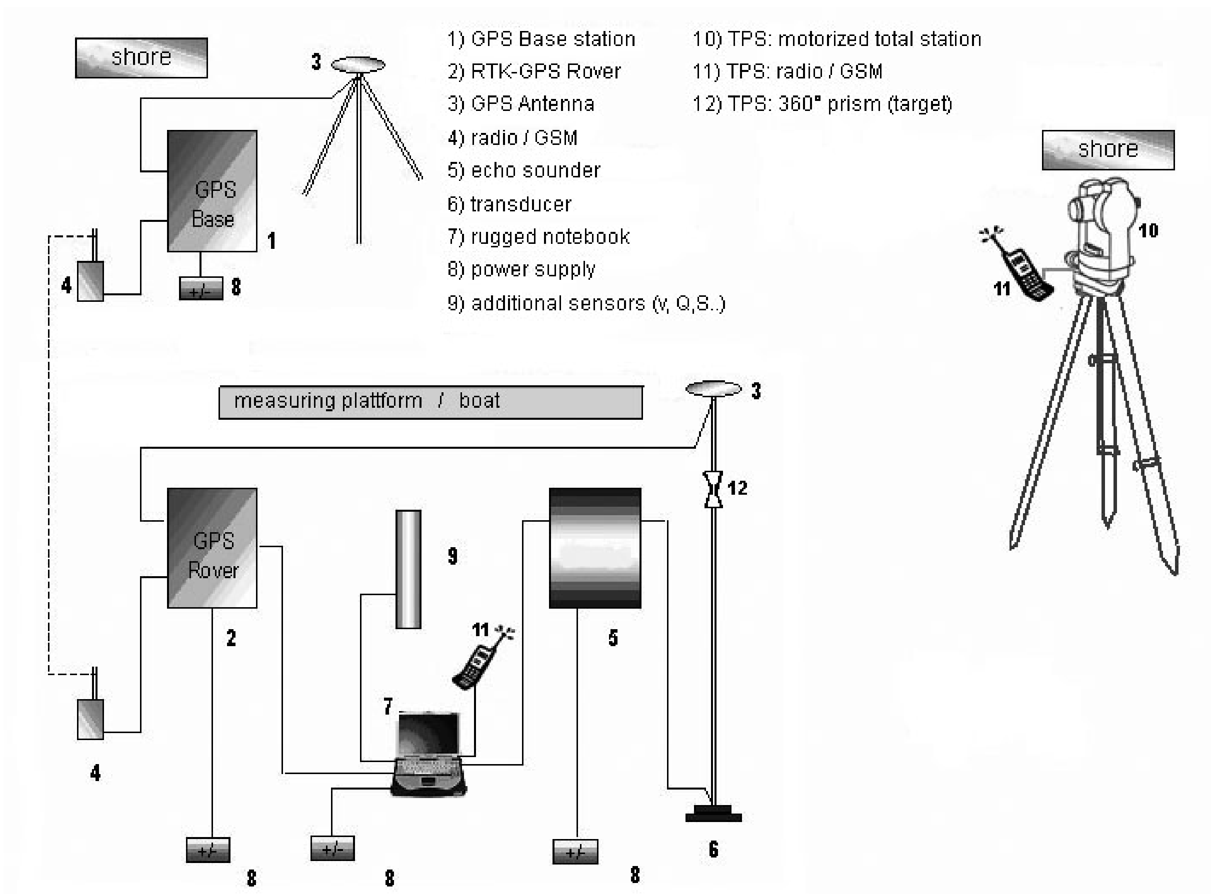

Fig.4: Configuration of the measuring system

3.2 Measurement Process

In most cases, on small rivers, you cannot determine in which section you will experience a loss of signal. To guarantee efficient application of the system in the field, TPS remains in “standby mode” while the measuring platform is in the process of using GPS. This does not mean that TPS is not active at this time. During this time, the TPS operators are surveying the surrounding area, such as the river bed, the alluvium etc. In a section where loss of GPS positioning is experienced, the TPS operators receive notification via mobile phone from the crew on the measuring platform that their services are required. While the TPS operators move to the area of signal loss, the measuring platform continues measuring along the river. Once the TPS operators are in position, they call the measuring platform back. At this point, TPS is used to determine the trajectory of the platform. The data link between TPS and the measuring platform is established by radio link. The resulting hydrographical survey data is stored in a central CPU, located on the measuring platform.

There are two constraints with using TPS:

- Fog in the river section:

In these conditions, the operators on the measuring platform will notify the TPS team that measurements are not possible, and therefore to stay in position.

- Strong sun reflections on the water surface in the direction of the measuring platform.

This occurs especially when sun elevation is very low (Fig.5):
In this case, assessment is difficult because in the time delay between informing the TPS operators and their arrival, the sun may have shifted.

3.3 Calibration and Accuracy Analysis

The practical application of the measuring system on small rivers shows us that the level of accuracy achieved in the field differs from those achieved under controlled conditions (such as a laboratory). Positioning errors of several decimeters can occur. To establish the source of these errors, investigations using the complete measuring system were undertaken on a tributary of the Danube River with very low current. The study was completed using the most up-to-date systems on the market, such as the RTKGPS Leica GX1203, and the TPS instruments Leica TCRA 1203 of the firm r&a Rost and the Trimble ATS of the firm Geodäsie Austria. Besides the question of how to synchronize the stand-alone systems, the main question was how TPS performs when the movement of the prism on the measuring platform is erratic due to highly turbulent water conditions (waves, current changes etc). Such movements occur especially when surveying areas in which troughs or other notable deformations of the river bed have been created.

The results of the first analysis show that, for the same position, notable differences in coordinates were achieved by the different positioning systems (Fig.6). Further analysis of data, as well as further measurements, have to be undertaken in order to ascertain the reason for these anomalies.

Fig.5: Disturbing sun reflections

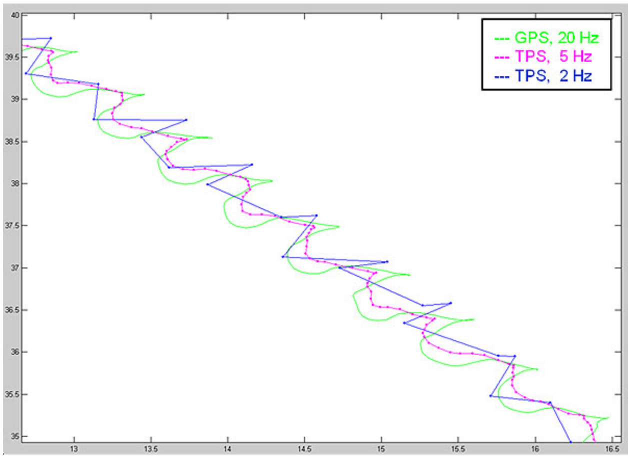

Fig.6: Boat trajectory - result of three different positioning methods

4. PRACTICAL IMPLEMENTATION

4.1 River Bed Measurement of the Stilling Basin in the City of Salzburg

Due to a high water occurrence in August 2002, there was substantial damage to the weir of the river Salzach in the city of Salzburg. The question was whether the stilling basin had suffered damage, thus resulting in the high water occurrence. Assessing this situation required a highly reliable and accurate measurement. Due to difficulties posed by the strong current, standard measuring methods were not applicable in this area. A 450m length of the basin was surveyed by cross-sections every 30m. In the area of the weir, the space between the cross-sections was shortened. As a result of the combined application of RTKGPS/TPS and an echo sounder, the required section of river could be measured with accuracy in height greater than 10cm. The resulting height of the basin floor was imported into a DTM program, and a digital terrain model created with 25cm grid spacing for use in further analysis (Fig.7).

Fig.7: Application of the coupled GPS/TPS positioning unit for measuring the stilling basin in the city of Salzburg and resulting digital terrain model of the basin floor

4.2 Riverbed measurement of the Salzach in the area of Oberndorf/Laufen

A notable feature of this section of the river is that the current is continually eroding a channel down the centre of the river bed. A surveying team was required to assess the extent of erosion, to a highly accurate level. This type of structural erosion can only be determined by very dense cross-sectional measurement, spaced every 10m. Figure 8 shows on the right an example of the measurements taken, and on the left the resulting DTM.

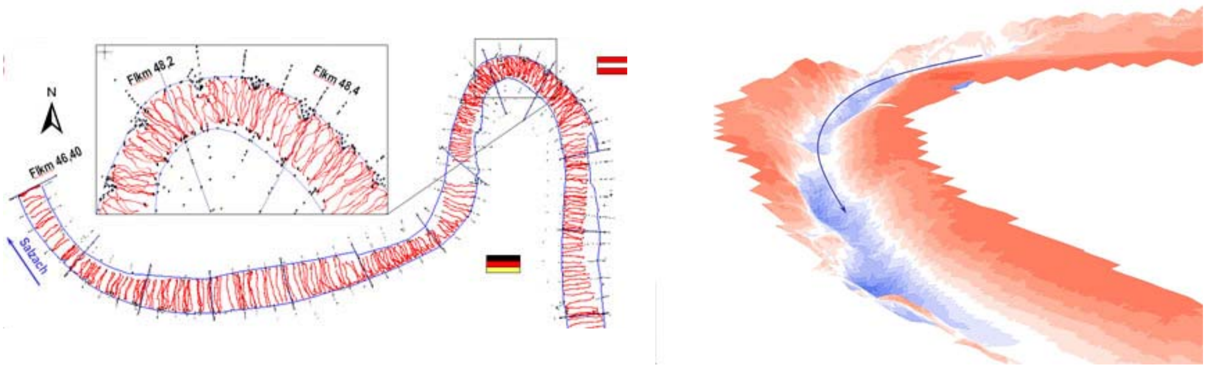

Fig.8: Bow of river Salzach at Oberndorf, Austria (Laufen, Germany)
Example of profile measurements taken — Perspective view of the resulting DTM

5. CONCLUSION AND OUTLOOK

A modular hydrographic surveying system for tributary rivers has been developed by the University of Natural Resources and Applied Life Sciences, Vienna in cooperation with Mayr&Sattler, a private company specialized in river management. Narrow stream courses and turbulent flows cause big pitch and roll movements as well as acceleration torques to the small and flexible survey vessel (boat). By combining state of the art RTKGPS sensors and TPS sensors these high frequent and discontinuous trajectories can be described with an accuracy enough even for multi beam echo sounding operations on alpine rivers. The efficiency of the methodology has been demonstrated in several practical applications on alpine rivers in Austria. Nevertheless, abrupt changes of the direction and the acceleration of the boat roll movement led to failures in the determination of the position.

Therefore, further investigations on the performance of TPS sensors have to be undertaken relating to the quality of measurements at trajectory turning points.

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BIOGRAPHICAL NOTES

Erwin Heine currently works as an Assistant Professor at the Institute of Surveying, Remote Sensing and Land Information at the BOKU - University of Natural Resources and Applied Life Sciences, Vienna (BOKU Wien). In 1992 he obtained his Master's degree in surveying and in 1997 his PhD degree at the University of Technology in Graz. Between 1993 and 1998 he worked as a researcher at different international sites (Mexico, Nepal, Germany, and Spain). His research work is focusing on engineering geodesy and GPS based positioning and navigation, which is also lecture topic of the BOKU master's program "water management".

Peter Mayr is working as a civil engineer for water management and hydraulic engineering in his own company - Mayr & Sattler OEG. The company is specialized on Hydrographic surveying, Hydraulic Modelling, Bed Load Modelling and GIS. From 1998 to 2003 he worked as a researcher at the University of Natural Resources and Applied Life Sciences (BOKU Vienna). Peter Mayr is member of the COST action 626 – European Aquatic Modelling Network.

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