University of Pécs

Usability Analysis of Recreational-grade Bathymetric Sonars in Shallow Rivers

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1 Introduction

Compared to other geodetic survey techniques the morphometric surveys of river bottoms started quite lately in the Age of Discovery to provide safe harbors for commercial ships. This period was also the firs golden age of cartography.

In this era river bottoms was mapped by measuring rods and weighted ropes.

Pieter BRUINSS, who draw the first contoured map of the *Spaarne* River in 1584, made the first breakthrough in cartographic relief representation and depth mapping.

His map depicts the areas in the river where the depth is greater than 7′. This was the first application of isobaths.

Later, in 1730 Nicolaas Samuel CRUQUIUS (1678–1754) started to promote this technique in wide range of river bathymetry (Figure 1.).

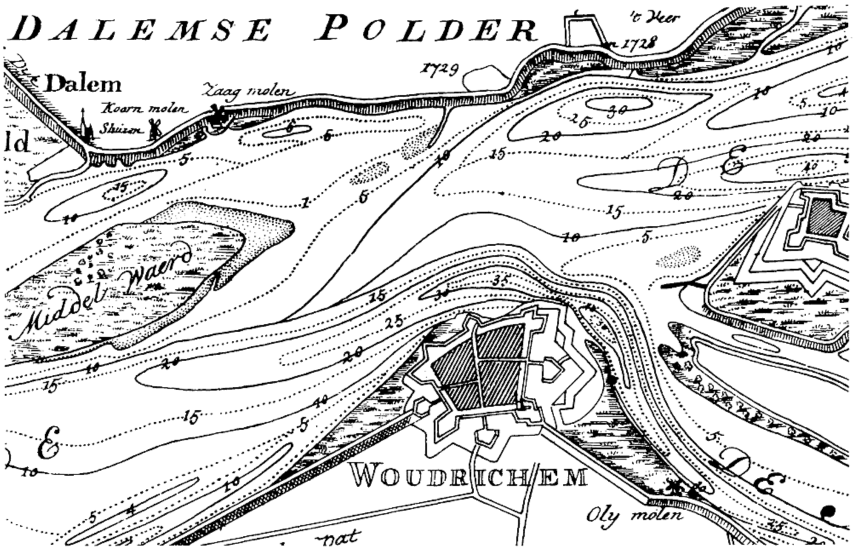

Figure 1. The isobath map of Nicolaas Samuel CRUQUIUS about the Maas and the Waal rivers. The original scale was about 1 : 110 000.

In the 19th century, these isobaths emerged from the water and went to the land: this was the down of contoured maps.

The second revolution of bathymetry was born immediately after the *RMS Titanic* sunk in 1912 into the deep.

After this event, a Canadian physicist, Lewis Fry RICHARDSON (1881–1953) submitted a patent about a device, which was actually the first active sonar. After an enormous development campaign in electrophysics and hydroacoustics, this invention transformed into the modern, digital sonar.

Originally, the sonars were expensive and professional tools, but after the evolution of electronics, these units gradually transformed into affordable devices. After a threshold was reached, hobbyists started to buy these units as recreational-grade fish-finder sonars.
This dissertation deals with the bathymetric, interferometric recreational-grade sonars.

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2 Objectives

The main objective of this research is to assess the usability of the interferometric, commercial, recreational-grade sonars on the Hungarian section of the Drava River.

The research was divided into 8 steps:

1. To select a low-cost bathymetric sonar.
2. To design and build a survey system based on the low-cost sonar.
3. To process the sonar readings.
4. To select an optimal interpolation tool.
5. To map the Hungarian section of the Drava River.
6. To revise the shipping routes.
7. To compile a hydrographic atlas.
8. To develop a standardized protocol to use recreational-grade sonars in rive surveys.

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3 Tools & Methods

3.1 Recreational-grade sonars in river bottom surveys

The development of sonar-systems are usually initiated by a need declared by the military and/or the intelligence.

This fact made the military the primary user of advanced sonar technologies. Later the professional commercial and scientific applications also start to spread which was a huge step forward in the field of ocean bottom mapping.

Due to their physical dimensions and vulnerability of the professional side-scan, multibeam and interferometric sonars they could not be used in shallow rivers.

Meanwhile, thanks to the evolution of electronics, the sonar vendors released several smaller, more rugged and more affordable alternatives of professional sonars. These sonars commonly referred as recreational-grade, or fish-finder sonars.

Researchers from several fields of hydrology discovered the potential in the last 5–10 years of these sonars.

Disadvantages of the recreational grade sonars:

- The technical details are unknown (impulse type, length of impulse, power, signal to noise ratio, detection angle etc.)
- The post-processing of recreational-grade sonar reading is neither standardized nor well documented. The internal preprocessing algorithms are unknown.
- The position of the sonar, the heading, pitch and roll information are either unknown or approximate.
- The output file formats of recreational-grade sonars cannot be processed by professional sonar post-processing software.

Advantages of the recreational grade sonars:

- The price of a recreational-grade sonar is about $^{1}/_{20}$ of a professional sonar.
- They are rugged, lightweight and maintenance-free; they can be mounted on various platforms.

- The installation and usage of these sonars will not need a special training or education.

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3.2 Principles of interferometric sonars

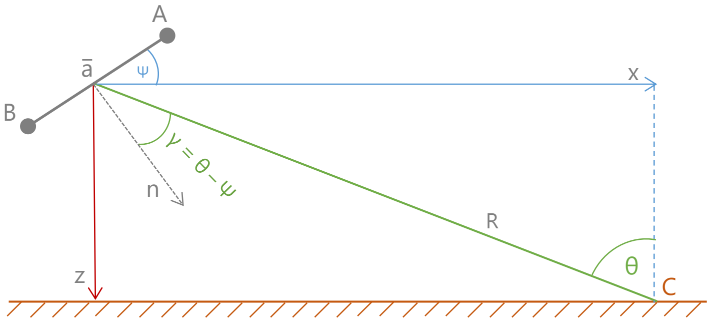

Figure 2. Principle of interferometry. See the explanation of the letters in the text above.

We can easily convert the side-scan sonars to an interferometric device if we install two or more hydrophones next to the central transducer body with phase recording capability. The hydrophones should be installed on both sides of a section, which has inclination of 30–60° degree.

If we know the length $a = \overline{AB}$ section (Figure 2.) and the *'Ψ'* angle measured from the horizon and the length of the *'R'* section coming from traditional sonar ranging then we can calculate the *'θ'* angle with the following equation:

$$\Delta\varphi_{AB} = k\delta R = ka\sin\gamma = 2\pi\frac{a}{\lambda}\sin\gamma \qquad \{1\}$$

where $'\Delta\varphi_{AB}'$ is the phase difference measured between *'A'* hydrophones *'B'* (Figure 2. and 3.); *'λ'* is the wavelength; *'k'* is the key number $\left(k = \frac{2\pi}{\lambda}\right)$; *'γ'* is the angle between the normal vector of the $\overline{AB}$ section and the *'R'* section; *'δR'* is the difference of length of $\overline{AC}$ és a $\overline{CB}$ sections (LURTON, 2000).

We can express *'θ'* angle the equation {1}. with the help of $\gamma = \theta - \Psi$ (Figure 2.) as follows (LURTON, 2000):

$$\theta = \sin^{-1}\left(\frac{\Delta\varphi_{AB} + 2\pi\cdot n}{ka}\right) + \Psi \qquad \{2\}$$

where $n \in \mathbb{Z}$ ($n = \cdots - 2;\ -1;\ 0;\ +1;\ +2 \cdots$; see latter). With the help of this equation, we can calculate the *‘θ’* angle and if the length of *‘R’* section is already known we can specify the length *‘z’* and *‘x’* vectors.

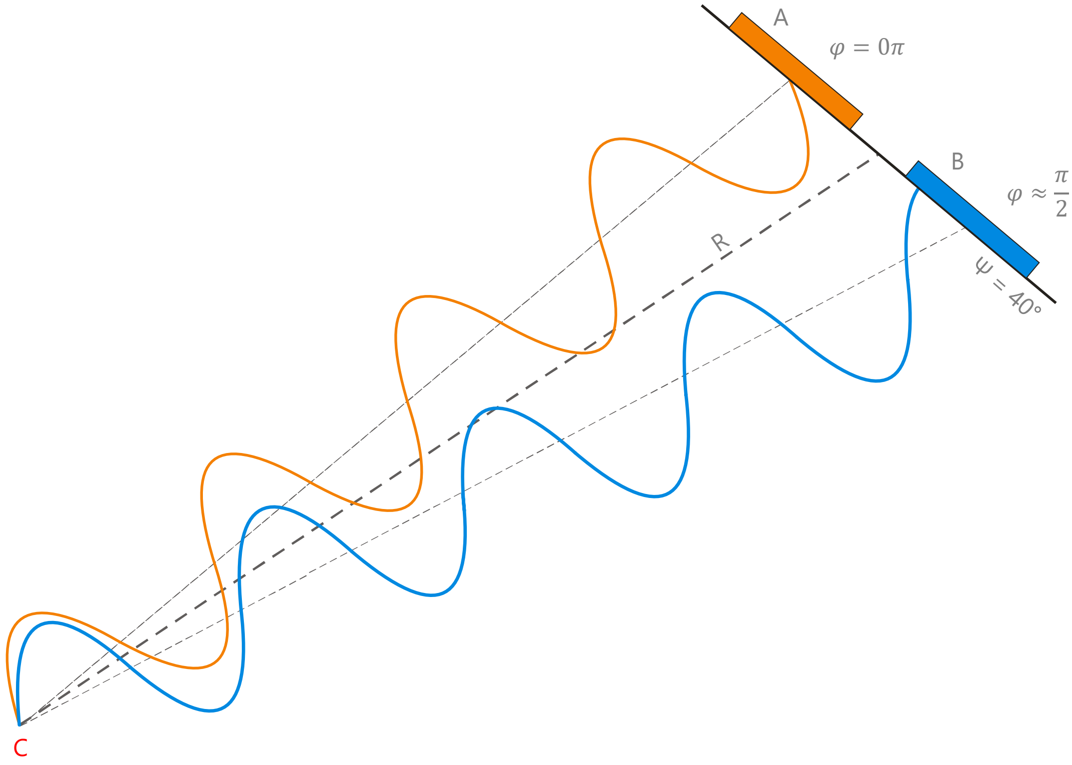

Figure 3. The practical detection of phase difference. See the explanation of the letters in the text and on Figure 2. The phase difference can be calculated with the following equation: $\Delta\varphi_{AB} = \varphi_B - \varphi_A = \frac{\pi}{2} - 0 = \frac{\pi}{2}$. *The phase in point ‘C’ is always the same. The wavelength and the size of the hydrophones are not to scale. The sinus curve is the visual representation of the displacement of the water particles in the longitudinal wave.*

However, ‘$\Delta\varphi_{AB}$’ cannot be measured as an absolute phase difference: the hydrophones are capable to register only the apparent, relative phase difference. If the reading on the first hydrpophone is $\frac{1}{4}\pi$ and on the second is $\frac{3}{4}\pi$ than the phase difference is $\frac{2}{4}\pi$. However, we cannot rule out that the absolute phase difference is bigger than 2π. That is why we have to introduce the *‘n’* multiplication in equation {3}. This fact introduces serious uncertainty in the calculation: in case of identical ‘$\Delta\varphi_{AB}$’ phase difference values we can get multiple *‘θ’* angles. In this case, the sonar’s central processing unit should select the correct angle based on the neighboring points and probability theory.

According to this fact the Lowrance® StructureScan® 3D gives us the length of the *‘z’* and *‘x’* vectors.

The calculation is always made in a plane so we can deal with the results as the coordinates of a polar coordinate system where the *'C'* point is the origin. Even in this case, these readings are unsuitable for bathymetric surveys.

To convert these polar coordinates into real-world projected coordinates we should know the heading, pitch and roll values of the boat and actual position of the transducer—which usually comes from a GNSS.

If these values are known, we can simply project the sonar readings into real space and apply these devices as bathymetric sonar.

Unfortunately, the length of the *'z'* vector can be calculated with a certain amount of error as we move farther away from the normal vector of $\overline{\mathrm{AB}}$ section.

We can calculate the amount of the error with the following equation:

$$\frac{\delta z}{z} = \frac{\delta \Delta \varphi_{AB}}{2\pi} \cdot \frac{\lambda}{a} \cdot \frac{\tan \theta}{\cos \gamma} \qquad \{4\}$$

The amount of error depends on the accuracy of phase difference measurement; and the ratio of the tangent of 'θ' angle and the cosine of 'γ' angle, where $\gamma = \theta - \Psi$ (Figure 2.).

4 Discussion

4.1 Components of the applied sonar system

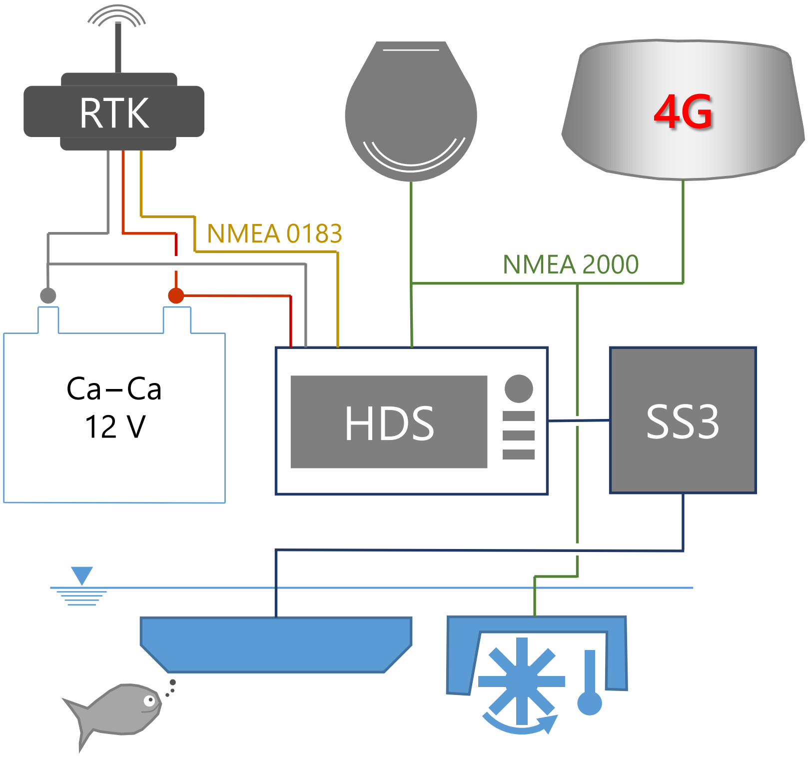

Figure 4. The schematic model of the applied sonar system.

The schematic model of the applied sonar system is presented on Figure 4. The system comprises of:

- An "HDS" module (second row, central device). This HDS module (Lowrance® HDS–7″ Gen3 Touch, OS Ver.: 5.0 – 57.1.219) is the central device of the measurement system. The HDS module is a modified tablet in a reinforced casing with a touch screen, with NMEA2000 and NMEA 0138 connectors, and sonar controllers. On the right side of the device there are two microSDHC™ slots to store the sonar readings. The HDS unit is connected with every peripheral.

- A GNSS (first row, left side). In our configuration, the GNSS was a GeoMax® Zenith35™ Pro Rover with UHF & UMTS modems for high-precision RTK+ measurements. This GNSS is capable to receive GPS L1/L2, GLONASS (ГЛОНАСС), BeiDou (北斗导航卫星系统) and Galileo signals. The field controller device of the GNSS was a Panasonic FZ-B2 TAB 7″ tablet.

- A Lowrance® Precision–9 (SW Ver.: 9.2) gyroscope to measure and counteract the heave, pitch and roll movement of the boat.
- A Lowrance® Broadband 4G™ Radar (first row, right) to detect the banks of the river. This part is optional and it was not included in the final configuration.
- A Lowrance® StructureScan® 3D (SW Ver.: 5.0 – 57.1.219; third row, left). This device is the main interferometric sonar with side-scan and DownScan capabilities.
- A Lowrance® EP-70R water speed and temperature sensor (third row, on the right). This sensor is used to detect the relative speed of the acoustic medium.
- A battery (second row, on the left) to provide 12 V D.C. for the system. The battery could be a standard Ca–Ca battery for cars.

4.2 Summary

The implementation of the survey was divided into three separate subtasks:

1. Literature and technology analysis (2017)
2. Design of the system (2017)
3. Software development, cartographical preparations and field measurements (2018–2019)

The outcomes is summarized in the order of objectives:

1. After comprehensive laboratory and field-testing, I selected successfully an interferometric, low-cost, recreational-grade sonar to provide an affordable alternative for shallow river mapping. I presented my findings on GDi Hungary's ESRI User conference as a plenary speaker.
2. I designed and built a front console for the sonar to enhance the imaging quality. This console provides a perfect fit for the single-beam, the interferometric sonar heads and for the water speed gauge. Because of the axial design of the console, we can reduce the geodetic inaccuracies if the GNSS is mounted on the top of the axis.
3. I developed a dedicated software to process the sonar readings.
4. I developed a data assimilation technique to merge the 3D bathymetric data with the pre-existing geodetic datasets—with an adequate interpolation method.

5. I surveyed the selected section of the Drava River. I assessed the roughness of the river bottom with the help of the additional side-scan images.
6. With the help of shipping specialists, we decided to redraw the sipping routes based on this survey.
7. I created a new hydrographic atlas of the Drava River with help of these new sonar readings.
8. According to the aforementioned proceedings, I designed a standardized procedure, which allow us to conduct a sonar survey based on any kind of recreational-grade sonar systems, types and vendors.

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