Innovation Memorandum
Hydrographic Surveying

Author: Dany Robberecht – Verhaert

INNOVATIEF AANBESTEDEN

Table of contents

1 Situation

Hydrographic surveying are three-dimensional surveys allowing the topography of the ocean floor and river beds to be mapped. The Flemish government annually spends around 10 million euros on hydrographic surveying of the Belgian part of the North Sea and the Scheldt estuary. To do so, the Flemish government not only relies on its own services (Agency for Maritime and Coastal Services, Coastal Division, Flemish Hydrography Team), but also several external parties, with several ships conducting these soundings on a daily basis.

To conduct these bathymetry surveys, acoustic monitoring systems are used such as *single-beam* and *multi-beam* equipment. In addition to bathymetry surveys, the topography of the beach, dynamic dunes, mud flats and salt marshes at the Belgian coast and in the Scheldt estuary are continuously monitored by means of *airborne laser scanning*. The acquired data are further processed into accurate LAS files and categorised into ground level points (all points on the ground level surface), non-ground level points or vegetation points (all other points, except spikes and inaccurate points) and water points. These LAS files are then processed into area-covering digital elevation models (DEMs).

The survey results of both *echosounding* measurements and LIDAR recordings can be processed into area-covering alti-bathymetric grids, allowing the Flemish Government to calculate difference maps, volume measurements and cross-sections over large areas and from bank to bank. Currently, these alti-bathymetric grids are processed manually, using different software packages and different interpolation methodologies depending on the source data.

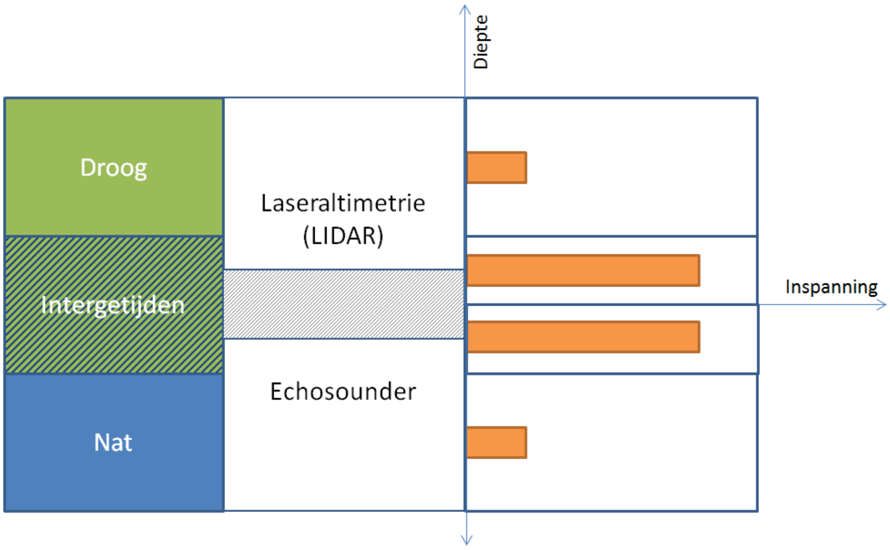
These results are used:

1. To produce nautical maps
2. To steer day-to-day maintenance dredging for the Flemish ports
3. For strategic applications (research)
    a. Morphological analysis
    b. Habitat maps
    c. Numerical models

The current survey technologies, i.e. the combination of echosounding and LIDAR, require a **great deal of effort to efficiently measure the intertidal zones** with the **required accuracy**. The LIDAR recordings are made at low water to measure an as large as possible vertical range. Conversely, the *multibeam echosounding* (MBES) surveys need to be made at high water to ensure a maximum vertical overlap with the LIDAR surveys. Considering the short timeframe (approximately one hour, because surveys need to be conducted at low and high water, respectively), the complexity of the measurements and the frequent use for such area-covering DEMs, efficiency gains are minimal;

on the other hand, this innovative issue is aimed at obtaining an integrated result of the dry and wet zones, respectively. The above-mentioned arguments are schematically summarised in Figure 1.

Diepte = depth



inspanning = effort

Droog = dry
Intergetijden= intertidal
Nat = wet

Figure 1: Current methodology for altimetric (LIDAR) and bathymetric (echosounding) data surveys

The use of hydrographic surveying is required for three high-priority objectives:

1. Guaranteeing safe shipping.
2. Monitoring and steering of maintenance dredging.
3. Research and monitoring with regard to eco-morphology, etc.

2 Issue focus

The Scheldt estuary has a special economic value as a direct gateway to the ports of Antwerp and Rotterdam. The area is also governed by Natura 2000, ensuring the future of Europe's most vulnerable animal and plant species and their habitats. In the Natura 2000 areas all member states of the European Union take measures to give European species and their habitats opportunities for the future as well.

The Scheldt estuary and Belgian part of the North Sea cover an area of +4,000 km² and are very complex; they have a high turbidity (muddiness of the water), are a high-traffic zone, have a mix of fresh and salt water and a varied soil composition. The master plan proposes the development of a new technological system to speed up the bathymetric data processing and production of an area-covering digital map, at an acceptable cost.

The current method for creating a digital map of the Scheldt estuary and the Belgian part of the North Sea is based on two sensor technologies; i.e. 1) multi-beam echosounders (MBES) and 2) LIDAR, mostly for topographical purposes. This results in a survey frequency that is too slow for an area-covering map. The Belgian part of the North Sea is updated every 7 years, the Lower Scheldt and the Western Scheldt annually and the Upper Scheldt every two years. The above-mentioned technologies are a labour-intensive survey process and the creation of a digital map is complex, resulting in a long processing, e.g. because the various survey zones including the overlap need to be calibrated. The availability of recent data on a frequent basis at a reasonable cost is impossible with the current technologies. After all, it results in a significant expansion of the fleet and resources. Ideally, Maritime Access has a dynamic digital base map with bathymetric information. At least an annual update of the area-covering map at a reasonable cost would be a significant step forward.

Data acquisition in the channel by means of MBES amounts to €540/km² on average; however, the shallow zones, or the intertidal area, cost a multiple thereof. The intertidal area covers at least 40% of the total surface area of the estuary. Today, Maritime Access has barely any bathymetric data on this area, because some zones cannot be sounded with the technologies currently used.

An additional problem is the interpolation of the sounding data. In practice, data on large floor sections are missing, resulting in estimates which de facto produce an inaccurate end result.

During the project, 6 use cases were investigated taking into account their added value and complexity:

1. Seamless integration of topographical area with bathymetry
2. Validation of the ocean floor topology (validation of the digipol algorithm)
3. An improvement of the sounding programme – currently periodically – by monitoring real-time dredging-critical zones (e.g. by means of radar)
4. A digital model of the entire estuary based on Airborne Electromagnetic Bathymetry sensors, a new technology which is not used today.
5. Advanced image processing algorithms and processes based on a fusion of (remote) sensing techniques.
6. A parameterised physical model of the composition of the soil/water column to make the surveys more efficient and to obtain additional data (morpho-ecological)

The figure below shows the estimate made together with MOW after a study of both the technology and the respective business cases:

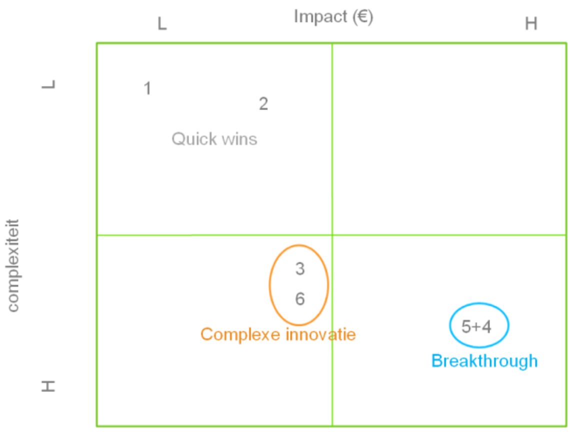


Figure 3: Weighing of the respective use cases

The project resulted in the combination of cases 4 and 5 (implementation of new sounding technologies) and 6 (soil and water column composition), which could also be of interest because of the predictive possibilities introduced into the project as a result thereof.

The project we currently propose is aimed at the development of an innovative toolbox in order to obtain a digital map of the entire Scheldt Estuary (incl. the Belgian Continental Shelf) using sensor fusion of existing sensor technologies, as well as technologies not used in the marine industry, centred around advanced signal processing technology.

In addition to bathymetry, the project is also aimed at knowing the composition of the water column, and particularly the detection of sediment clouds. After all, these have an adverse effect on the survey results from passive optical survey technologies (e.g. LIDAR) on the one hand; on the other hand, they do not allow MBES surveys to be conducted simultaneously with dredging for the steering and control of this process.

Finally, the project wants to provide an answer as to a reliable detection of the soil composition. Overall, the Scheldt estuary has 3 sediment types: silt, fine sand and sand.

Currently, survey data are lacking with regard to sediment transport as well as eco-morphological purposes.

The figure below outlines the proposed system:

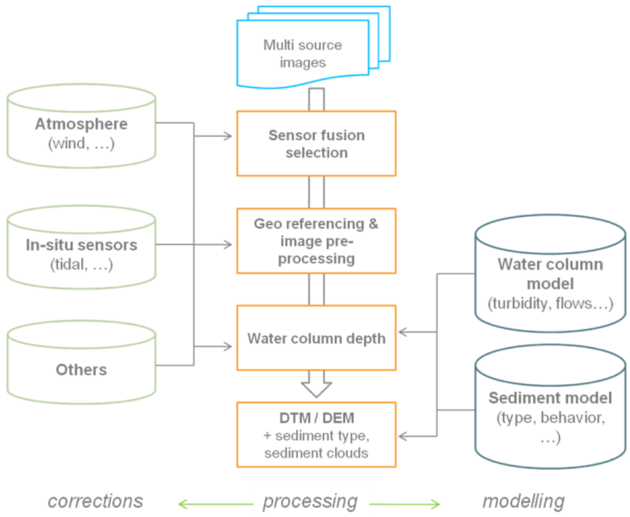


Figure 4: Framework of the proposed solution

The project is aimed at combining existing technologies (MBES/SBES/LIDAR) with remote sensing technologies and new modelling principles.

Various technological disciplines were taken into consideration:

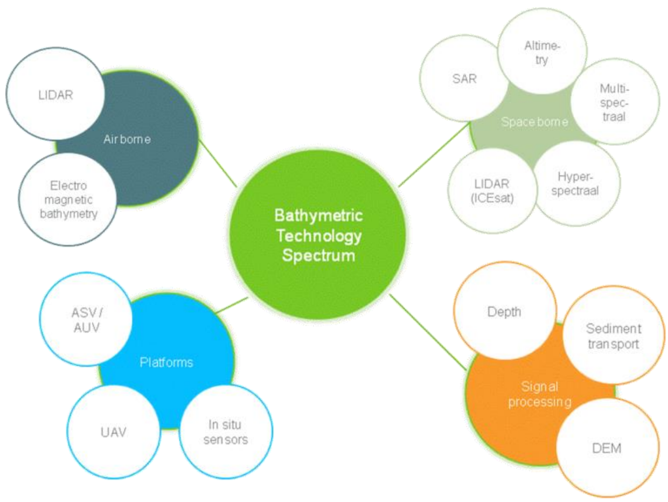


Figure 5: Scope of the technological orientation

3 State of the art

Among the current commercial services we often find, in addition to acoustic methods, solutions based on the principle of optical image processing. These technologies derive the depth from light reflection. However, light reflection decreases as the light absorption increases a) due to the water column composition (light propagation on turbidity, algae, …) and b) due to the depth. The technology produces good results in areas such as the Gulf of Mexico, Australia, etc. where the circumstances (clear water) are ideal for such technologies. Commercial providers achieve accuracies of 10% and survey up to a water depth of 30 m.

However, the results significantly deteriorate in more complex areas, such as the Baltic Sea and Caspian Sea. In practice, as a rule of thumb, LIDAR images can be enhanced up to 2.5 times the Secchi depth (a measure for depth-clarity measurements). Concretely, this means that the vertical accuracy is 15%-20% for a maximum water depth of 8 m.

The Scheldt estuary is an extremely complex area with a visibility that is often less than 30 cm and therefore requires other technologies. We would like to quote a world-class authority on optical image processing, Prof. Legleiter, Department of Geography University of Wyoming: "*I think your river of interest will be a very challenging case for passive optical remote sensing. The combination of high turbidity, muddy substrate, and relatively large depths imply that the bottom probably would not be detectable by most imaging systems, or would at best provide only limited information. I suspect that green lidar might be a little better, but not by much – I wouldn't get my hopes for that approach, either.*"

An overview of the various technologies and their current performance:

Sensor	Carrier	Availability	Dependencies	Depth	Accuracy
LiDAR	Airplane	Commercial	Turbidity, seabed adsorption, breaking waves (surf)	15-60m	
AEMB (Airborne Electro-Magnetic Bathymetry)	Airplane	Research	Resistance water and ground Unaffected by turbidity and surf		0.3m-0.5m in water <10m 1m – 2m in water >10m
Multispectral Imagery	Airplane		Turbidity	25-30m	- 15-20% - lower than LiDAR
Multispectral Imagery	Satellite	Commercial	See above + clouds	20m	10-20%
Hyperspectral Imagery	Satellite	Commercial	See above	20m	
LiDAR	Satellite	NASA	See airplane LiDAR + clouds		
MBES	Vessel	Commercial	Not for shallow waters	500m	10cm / 15m depth
…					

Figure 6: overview of commercial technologies

In this research stage, various technologies have been identified that may be essential to finding a solution; they are mainly based on indirect surveys on the one hand and advanced depth prediction models on the other hand:

<u>AEMB-Airborne Electro-Magnetic Bathymetry</u>

This technology is not yet commercially available, but is only applied in research projects such as a project in Broken Bay, New South Wales, where an accuracy of 0.3m to 0.5m was achieved for water depths up to 10m. For water depths up to 30m, an accuracy of 1 to 2m was achieved. This technology is independent of the turbidity or presence of breaking waves, but the challenge mainly consists in analysing the contribution of the separate resistance of the water column, sediment and bottom.

<u>Bathymetry from inverse wave refraction</u>

This technology uses the returned energy from a radar system. Tests have already been conducted with e.g. a Furuno X-band Radar with horizontal polarisation. In addition, other parameters are required as well, such as wind speed, wave height, current velocity and reference bathymetry. The vertical resolution is 10-20% of the depth and the horizontal resolution is 1 km. This technology can be applied in case of turbid water. More information: http://www.vliz.be/wiki/Bathymetry_from_inverse_wave_refraction

<u>WKB - Wave kinematics bathymetry</u>

This technology uses high-resolution satellite images and is based on the fact that waves slow down in shallower water. The difficulty is determining the wave speed. To do so, this technology uses two or more images with a precisely known time difference (1 to 20sec). The vertical resolution is 5-10% of the depth; the horizontal resolution is 50-200m. It can be applied from space as well as from an airplane and in case of turbid water. However, this technology is not optimally suited to determine the bathymetry of a river.

In any case, the above-mentioned technologies outline opportunities, provided that they are combined with an advanced physical modelling of the Scheldt estuary and Belgian part of the North Sea. In addition to a digital bathymetric map, the project also wants to know the water composition and soil type. Currently, the water column composition is lacking, as well as an area-covering physical model of the Scheldt estuary based on bathymetry.

Within the scope of this project, clear objectives were set to relatively define the degree of innovation compared to the current state of the art:

Issue	Delta compared to current situation
Data acquisition within a period of 1 week	Currently, this takes months or even years on the Belgian Continental Shelf
Survey of the entire depth range of the estuary (0-50m) resulting in a map of the entire estuary	Today, typically the channel: 10m-17m
Map production within 2 months, ideally a continuous real-time system based on prediction	Process improvement by at least a factor 2
The same depth accuracy as the current digital elevation models derived from an MBES sounding*	MBES is the most accurate source data currently available. Other survey technologies (see above) are a factor worse
The same (spatial) resolution as the current digital elevation models of an MBES sounding	

** Also, **minimum requirements** were set because of the complexity: accuracy of the DEM:*

- *with the same depth accuracy as the current DEMs derived from an SBES sounding*
- *with the same (spatial) resolution as the current DEMs from an SBES sounding*

- *The above-mentioned accuracies must be achieved in at least one of the two depth zones:*
  - *in shallow (**0 – 7 m**) turbid waters and adjacent intra- and supratidal areas with data acquisition within a period of one week*
  - *in deeper (**10 - 17 m**) turbid waters*

Fulfilling these minimum requirements results in a significant improvement of the current data acquisition method for the creation of area-covering DEMs used for geomorphological analyses, for habitat maps and numerical models.

4 Feasibility of the innovation project

The current set of basic technologies is based on (in-)direct surveys and is either too expensive (MBES) or insufficient (e.g. LIDAR) for the intended purposes. The expected progress in these technologies does not allow us to rely merely on these methods for the proposed solution.

Consequently, the project is aimed at complementing the above-mentioned technologies and developing a drastically different methodology with a corresponding toolbox in order to arrive at an area-covering DEM more frequently.

Therefore other acquisition methods need to be explored as well, such as AEMB, SAR, hyperspectral images, etc. Numerous data are available which the principal can use for the new method. Naturally, these acquisition technologies require new processing methods, including correction models to arrive at an altimetric bathymetry.

Currently, we are assuming that various technologies will need to be combined, probably using partial image information, in combination with a predictive model based on the physical behaviour of the water column and the sediment, in order to exceed the minimum objectives.

Considering the current state of the art, this project sets a very ambitious goal. Nevertheless, there are sufficient indications that this R&D project must be considered extremely complex yet feasible. Consequently, Maritime Access imposed several minimum performance requirements which will undoubtedly enhance the feasibility, but are also more in keeping with the various competencies/disciplines, backgrounds and knowledge levels of the actors (knowledge institutions & industry). Even these proposed minimum requirements remain ambitious, considering that they are not feasible with the current acquisition methods and processing technologies.

For that matter, the project includes various subaspects which are indispensible to achieving the final objective. In particular, we must mention the physical model of the water column, the behaviour of sediment, sensor fusion technologies, correction models (e.g. sediment clouds, atmospheric, …), soil composition, etc. They are de facto an important added value compared to the current situation.

Thus we conclude that the project can be considered feasible, in spite of its complexity.

5 R&D content within the project

The innovation perspective involves various aspects. First of all, technologically speaking, a new toolbox and process need to be developed. Considering the current state of the art, this is an important challenge requiring a significant technological progress in order to achieve the final objectives.

The project requires innovation and progress for all the stakeholders involved.

Maritime Access pursues a new acquisition and processing method; to achieve this, it must align its internal processes and existing infrastructure. We are assuming that new processes and infrastructure will need to be developed with regard to data storage, data mining, etc. Maritime Access will also develop new applications for morphological analyses and habitat mapping based on the project results.

As far as the contractors are concerned, we notice a significant shift from services providers using a single acquisition technology to multi-sensors. The project will result in a significant accumulation of knowledge regarding technologies and multidisciplinarity. Finally, the contractor must also develop an earning model and market route for this new technology.

The toolbox itself, i.e. the object of the contract, is extremely complex of course. Because the instruments are currently still in the (basic) research phase, they are not or barely applied on a commercial scale. Each of the subaspects is an intellectual challenge in its own right; their integration and the expected technological performance considering the state of the art will result in a high R&D content.