Published as: Stal, C., Deruyter, G., Paelinck, M., Vandenbulcke, A., De Wulf, A. (2015). Towards cost-efficient prospection and 3D visualization of underwater structures using compact rovs. Proceedings of the 15th International Multidisciplinary Scientific GeoConference (SGEM 2015), Albena (Bulgaria), 16-25 June 2015, pp. 1211-1218.

TOWARDS COST-EFFICIENT PROSPECTION AND 3D VISUALIZATION OF UNDERWATER STRUCTURES USING COMPACT ROVS

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ABSTRACT

The deployment of Remotely Operated Vehicles (ROV) for underwater prospection and 3D visualization has grown significantly in civil applications for a few decades. The demand for a wide range of optical and physical parameters of underwater environments is explained by an increasing complexity of the monitoring requirements of these environments. The prospection of engineering constructions (e.g. quay walls or enclosure doors) and underwater heritage (e.g. wrecks or sunken structures) heavily relies on ROV systems. Furthermore, ROVs offer a very flexible platform to measure the chemical content of the water. The biggest bottleneck of currently available ROVs is the cost of the systems. This constrains the availability of ROVs to a limited number of companies and institutes. Fortunately, as with the recent introduction of cost-efficient Unmanned Aerial Vehicles on the consumer market, a parallel development is expected for ROVs. The ability to participate in this new field of expertise by building Do It Yourself (DIY) kits and by adapting and adding on-demand features to the platform will increase the range of this new technology.

In this paper, the construction of a DIY OpenROV kit and its implementation in bathymetric research projects are elaborated. The original platform contains a modified webcam for visual underwater prospection and a Micro ElectroMechanical System

(MEMS) based depth sensor, allowing relative positioning. However, the performance of the standard camera is limited and an absolute positioning system is absent. It is expected that 3D visualizations with conventional photogrammetric qualities are limited with the current system. Therefore, modifications to improve the standard platform are foreseen, allowing the development of a cost-efficient underwater platform. Preliminary results and expectations on these challenges are reported in this paper.

Keywords: ROV, 3D visualization, underwater, prospection, cost-efficiency

INTRODUCTION

The pressure on waterways has increased tremendously since the beginning of the industrial revolution. The rationalization of spatial planning and the increased agricultural productivity have encouraged river canalization and the destruction of natural meandering river systems and fluvial ecosystems in general [1]. A large number of constructions (bridges, bank reinforcements, etc..) are constructed to facilitate this transformation in an orderly manner and to regulate the water balance with optimal safety. However, complex processes that take place under and just above the water have to be monitored carefully. Changes in water composition (whether or not linked to pollution), erosion, disintegration of civil engineering structures and sedimentation of river beds endanger the functioning of the interior waters. Although these mentioned examples are only a few processes that take place relatively slow, their consequences are extremely undesirable after a given point (of no return). The availability of tools to monitor these processes is therefore indispensable for the sustainable management of interior waterways.

In a Belgian context, the management of interior waters is a highly relevant policy area, which is painfully illustrated by frequent floodings in the Dender basin together with a growing demand for land areas with a high flood risk... In addition, the increasing number of barges augments the pressure on locks and quay walls. This causes a larger wastage of these structures, which need to be consistently and accurately monitored. Dangerous situations also occur when constructions near the water are abandoned. An example are the docks in Ghent (Belgium), which are about to collapse due to lack of proper maintenance. Finally, the intensive agriculture industry and the sewage systems have a huge impact on the flora and fauna of these waters. Large amounts of nitrates and phosphates flow into the surface water with all its consequences. Although concentrations of harmful amounts of additives are accurately measured within the framework of the European Water Framework Directive, an optical system for monitoring the environment near river banks and submerged areas is a must [2].

The responsible authorities (the Flemish Department for Transport and Public Works (MOW) for navigable waterways and the Flemish Environment Agency (VMM) for non-navigable waterways) have to make a thorough inventory of the quality of constructions on, along and in the water in the near future. In case of the monitoring of locks, the various compartments are periodically reclaimed. The passage of the locks is hereby temporarily obstructed, thus inducing economical loss. Furthermore, the lack of the water pressure causes additional stress on these structures, with risk of failure as a consequence. For maritime engineering projects, several opportunities exist to perform underwater prospection using robust, unmanned, remote-controlled underwater vehicles

(Remotely Operated Vehicle or ROV). However, the use of these systems involves a reasonable cost, limiting the deployment of these systems. In addition, the manoeuvrable space around the underwater constructions is normally extremely limited. This is especially true for horizontally aligned echo sounders for which the data acquisition and processing of vertical structures, like lock doors, is extremely complex.

Notwithstanding the increasing complexity and decreasing budgets of governmental tasks and the nature of the technical challenges to perform such crucial projects, a very compact and cost-efficient platform is required. Such a platform must allow underwater optical inspections and supervision, as well as the generation of 3D models of underwater structures. The platform must be constructed in such a way that it also can be deployed in real time and for other than geometric measurements, such as environmental related data acquisition. The demand for a solution to this challenge is important for government and commercial organizations. Recent developments in open-source ROV systems increase the working range of these systems [3]. An interesting consideration for addressing this problem, is the recent rise of cost-efficient and open-source robotics systems. These developments make a considerable range of hardware and software available for such research.

RESEARCH QUESTIONS AND OBJECTIVES

The lack of a proper methodology for the prospection and 3D modelling of waterway environments and river banks results in the question on how to fill this gap. For this reason, the following research questions are formulated:

1. What are the requirements to deploy the targeted prospecting techniques and 3D visualizations for a sustainable and efficient management of inland waterways?
Prior to deploying the intended platform, it is essential to optimally fit the characteristics of the system to the requirements for sustainable and efficient water management. In order to make 3D models for prospection, a digital camera with sufficient quality (sensor, lens, ...) is required. Also, for performing underwater surveys in the event of calamities, the fast availability of the platform is important. The analysis of these and other questions is to be considered as a feasibility study in which the boundary conditions are defined for the use of the system. Examples of parameters to be considered are the flow and the turbidity of the water, which can be limiting factors for the stability and manoeuvrability of the ROV.

2. What measurement platforms and methods are suitable for the collection of accurate observations and 3D models in shallow waters?

Previous research has demonstrated that mobile platforms are appropriate for the mapping of large surfaces. The question arises which kinematic 3D data measurement systems allow the acquisition of sharp images and the construction point clouds in shallow waters and shores of waterways. The focus will be on the use of images, since imagery provides both qualitative and quantitative information about the studied a phenomena. This second research question can be disentangled in:

a. the performances regarding geometrical accuracy, precision, resolution, range, repeatability and availability of such systems (separate systems and integrated static and kinematic ...);

b. the conditions that must be respected to achieve the integration of different systems (emphasizing time synchronization and data standardization);

c. the operationalization of such a system under the physical conditions of interior waters (taking into account current, wind, other water activities ...).

3. How to position a ROV relatively to a floating vessel, while acquiring data synchronously?

Apart from the integration of various components within the two sub-platforms (vessel and ROV), the coupling between the two systems is a substantial part of this study. A continuous synchronization is crucial for individual measurements above and below water, but also for the spatial and temporal coherence between the resulting two data sets. The positioning of the ROV in a spatial frame in general, and the location related to the vessel in particular, is a technological challenge, especially when a high cost-efficiency is envisaged.

4. What actions should be taken to deploy the system quickly and efficiently for urgent mission?

3D methods and techniques result in huge data sets. Processing these data sets includes the realization of spatial coherence between different elements in these data sets, as well as the filtering of erroneously detected surface points. Furthermore, a thorough error analysis is obviously required. The use of bathymetric measurement and processing software, image processing software and point cloud processing software is foreseen. The combination of software packages allows to create metric models of objects and areas underwater with a known spatial relation to phenomena above water.

METHODOLODY

Study area and boundary conditions

Based on the previously mentioned requirements for a platform for prospection above and below the water surface, the variability of potential study areas is large: harbour basins and docks, lock complexes, canals, rivers with reduced flow, lakes and ponds,... Especially the accessibility of the study area and the flow and turbidity of water are expected to be the biggest obstacles for the availability of the system.

The urge to prospect a large number and variability of features also implied the need for a considerable cost-efficiency of the system. The pressure on governments to do the same or more with fewer funds requires a highly flexible multi-purpose system. To date, underwater prospection is technically difficult and too costly, since highly specialized hardware is typically used.

The recent rise of cost-efficient and open-source robotics systems made available a huge arsenal of hardware and software for innovative researchers and other interested parties. This trend is already noticed in the 90s with the development of open software systems, but recently resulted in open hardware, such as multi-controllers (like the Arduino) or full-fledged computers (like the Raspberry Pi). So far, the use of these systems in bathymetry and geo-information is largely unexplored. Unmanned Aerial Systems (UAS) are an exception to this statement and has led to significant booming of airborne imagery applications.

The configuration of a system containing cost-efficient components, and the communication between these components and hardware already available, such as a digital camera or a Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS) receiver, is a challenge. Furthermore, these components should be mounted in a waterproof housing, and a power supply should be on-board with sufficient capacity.

Design of the platform and system

The considered platform is presented in Figure 1, illustrating the basic components of the system. The vessel includes a number of surveying devices that are typical of kinematic data acquisition, such as a GNSS RTK, an INS and a computer for project management. The offsets of the units must be measured accurately to ensure spatial coherence between the components. The ROV is connected to the vessel by a two-wired data cable. As a result, the size of the ROV remains limited, since no data storage is required on the platform. This allows the reduction of drift and loss of the device. For the mutual positioning of the vessel and the platform, acoustic baseline techniques will be used.

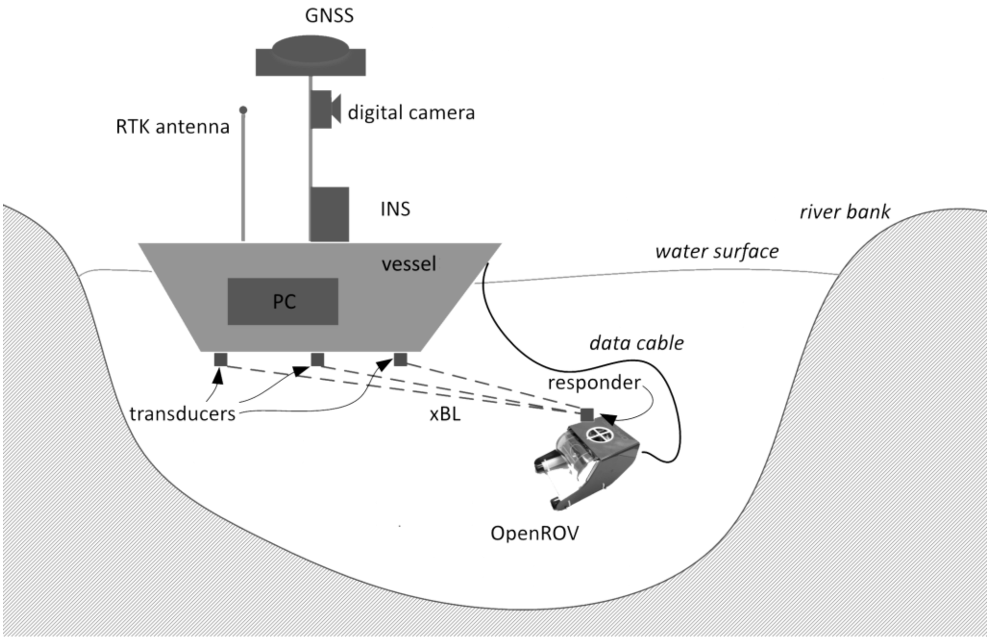

Figure 1: Schematic representation of the target platform with the main components

Construction of the ROV and performance study

An underwater vehicle of the type OpenROV is chosen for the construction of the platform (www.openrov.com, Figure 2). OpenROV is an open source hardware and software project, where the design of the system, the manual on standard construction instructions, the support and suggestions are provided by a very active community of users. The proposed platform is a remotely controlled mini underwater vehicle with a weight of about 2.5 kg and dimensions of 0.15m x 0.20m x 0.30m. The ROV is fuelled by a series of C batteries in the legs and is assembled using robust but common materials (mainly Plexiglas). The device is offered as a package of separate components (DIY) for about 900 USD, which is significantly cheaper than currently used underwater platforms. The core of the platform consists of a Linux computer, but an (on-shore) PC is required for controlling the system by an operator. Using the internet browser of this PC, the steering motor on the upper side and the two booster motors on the rear are controlled. All other commands are also sent via a cable, and imagery and system status information are received in real time. Furthermore, the ROV is equipped with a series of LEDs and a simple camera. Additional sensors (acoustic sounders, depth sounder, maybe sensors to measure chemical composition of the water) will be added and tested in the near future.

Implementation of the underwater localization

A physical connection between the vessel and the underwater ROV exists of a two-wired cable. In order to know the geometric relationship between the two platforms, a location measurement is necessary by means of a positioning (X,Y,Z), and orientation (ω, ϕ, κ) determination between the two platforms. The combination of these measurements allows the spatial coherence between data acquired above and below the water surface.

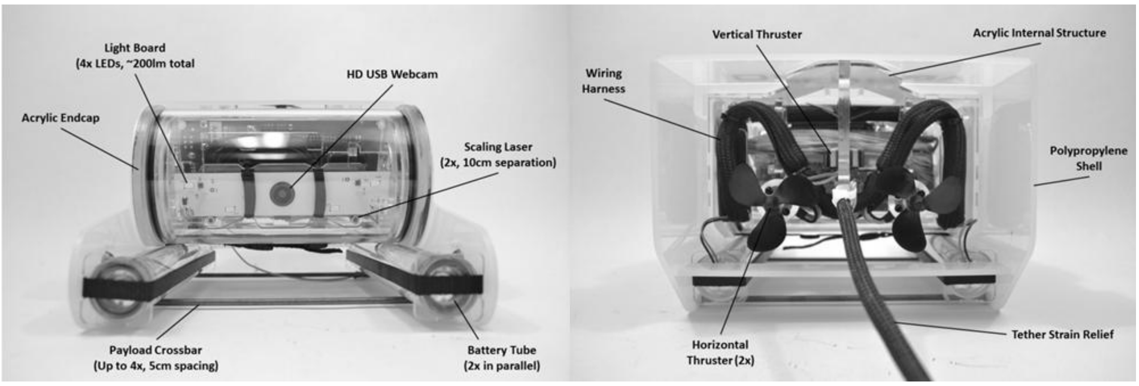

Figure 2: OpenROV front (left) and rear (right) (www.openrov.com)

Positioning

Acoustic radio positioning will be used for the positioning of the underwater ROV. In this case, a selection must be made between one of the following techniques [4]:

- Long Base Line (LBL): in this configuration, three hydrophone housings will be placed on the moving platform, while one responder will be fixed on the ROV. The ROV will receive an electric signal via a cable from the vessel, and answers this signal by transmitting an acoustic pulse back to the vessel;
- Short Base Line (SBL): instead of three hydrophones, only one projector will be mounted on the vessel. Three hydrophones on the ROV will capture, convert, transfer and processing the signal to a position;
- Ultra Short Base Line (USBL): for the last variant, a single projector will be placed on the vessel, which can transmit acoustic pulses to a single enclosure with three hydrophones on the ROV.

Initially, the LBL seems the most interesting technique, since more space is available for the installation of the hydrophone housings on the vessel. Test configurations are required to evaluate the accuracy of this configuration. In this context, an accuracy of a few centimetres is envisaged. The hardware will contain of a series of ultrasonic distance measurement devices, which are controlled using a microcontroller (Figure 3, left). It goes without saying that a watertight casing around the fine electronics is crucial. Finally, a conventional RTK GNSS with centimetre accuracy will be used for the absolute positioning of the vessel.

Figure 3: Ultrasonic distance meter for use in combination with a microcontroller (left, source: http://arduino.cc), integrated INS / GNSS system (centre, www.sbg-systems.com) and integrated IMU, compass and depth sensor (right, source: www.openrov.com)

Orientation

In addition to the positioning of the various components, the orientation parameters of the platform should be known. These parameters are usually calculated based on an Inertial Navigation System (INS, Figure 3, middle). This system consists of an Inertial Measurement Unit (IMU), and a processor for the manipulation of the data obtained from the IMU. These data include measurements from accelerometers, gyroscopes and magnetometers. An integrated INS can be supplemented with GNSS data and allows the estimation of a continuous path for the course of the platform. The temporal incoherence between the INS and the GNSS is adjusted using a Kalman-filter. Underwater measurements will be performed on a small MEMS-based motion sensor with integrated depth (pressure) and temperature sensor (Figure 3, right) [5].

Prospecting and 3D modelling upper and lower water

Recent photo modelling software is able to generate 3D models based on a large series of images using Structure from Motion and Multiview Stereo (SFM-MVS) [6]. SFM-MVS is a technique to reconstruct the camera recording parameters, and a series of characteristic points in a 3D scene using multi-stereo matching (SFM). Then, the technique used to calculate the 3D geometry of an object by projecting the images with reconstructed acquisition parameters in a 3D space (MVS). Either when the images are geo-tagged, or when an allocation of ground control points has occurred, SFM-MVS will result in a 3D model (or derivative) with a proper radiometric and geometric quality. These techniques will be applied to generate metric 3D models using images taken with a digital camera onboard of the vessel and with the camera mounted on the ROV.

Operationalization and system optimization

The development of a prospection and 3D data acquisition platform is a process of trial and error. It is also evident that the operationalizing- and optimization phase of the project goes hand in hand. Supplementing, modifying, adjusting and calibrating (new) components requires access to a controlled test environment. This iterative process will eventually lead to the most optimal system configuration.

CONCLUSION

The primary objective of this research project is to develop a ready-to-use, compact and cost-effective solution for 3D inspection, supervision and visualization of both objects above water (bridges, vegetation, slope reinforcements, and the other objects under the waterline (lock doors, siltation, underwater heritage, dumped waste, ...) in shallow waters (streams, rivers). This central objective can be divided into a number of sub-objectives, namely the definition of study area and boundary conditions, the design of the platform and the system, the construction of the ROV and a performance study. Furthermore, underwater localization (i.e. positioning and orientation) is fundamental for the construction of accurate 3D models of underwater constructions.

In summary, this project will result in an innovative procedure for creating imagery and 3D visualization of structures and phenomena under water and the close surroundings of these surfaces. In addition to the platform itself, these are also the tangible finalities of the proposed project. To achieve this project, system operationalization and system optimization is a final but essential phase of the project.

REFERENCES

[1] Jongman R., Külvik M., Kristiansen I., European ecological networks and greenways, Landscape and Urban Planning, vol. 68/issue 2-3, pp. 305–319, 2004

[2] Hering D., Borja A., Carstensen J., Carvalho L., Elliott M., Feld C., Heiskanen A., Johnson R., Moe J., Pont D., Solheim A., van de Bund W., The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future, The Science of the total environment, vol 408/issue 19, pp. 4007-4019, 2010

[3] Jessup M., Mesophotic coral ecosystems: tools and techniques for scientific exploration. Proceedings of the 33rd Symposium of the American Academy of Underwater Sciences, USA, 2014, pp. 14–21

[4] de Jong C., Lachapelle G., Skone S., Elema I., Hydrography. Delft, the Netherlands: Delft University Press, pp. 353, 2002

[5] Woodman O., An introduction to inertial nagivation. Cambridge, UK: University of Cambridge, Computer Laboratory, pp. 37, 2007

[6] Stal C., Van Liefferinge K., De Reu J., Docter R., Dierkens G., De Maeyer, P., Mortier S., Nuttens T., Pieters T., van den Eijnde F., van de Put W. & De Wulf A., Integrating geomatics in archaeological research at the site of Thorikos (Greece). Journal of Archaeological Science, vol. 45/issue May, pp. 112–125, 2014