RoBiMo – The tasks of scientific divers for robot-assisted fresh-water monitoring

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Abstract. As part of the RoBiMo project, a measuring system for holistic, spatially resolved recording of the condition and processes in inland waters is to be developed. This system should measure regular, continuous and spatially resolved parameters of water quality in stagnant inland waters. For that, the swimming robot "Elisabeth" from the TU Bergakademie Freiberg will be enhanced and used. The measurements are recorded and placed on a winch system using a measuring chain of sensor elements (like temperature, conductivity, turbidity). The ingress of groundwater should also be detected like the respiration process of the lakes. The navigation of the swimming robot takes place autonomously from a base station on the bank due to a network-independent connection. For the evaluation and visualization of the measurement results, the methods of artificial intelligence and virtual reality are used. Local and seasonal changes in the water body can be documented.

With scientific divers, a comparison of the measured values "ground truth" with water samples and in-situ measurements should be realised. For that, an intensive investigation is necessary. Furthermore, the scientific divers can manipulate the sensors in a targeted manner and check the functionality in situ. For obstacle detection the photogrammetry process and reconstruction are used and shown in an example of the Flodden quarry in Meissen, Saxony. The following text should give an overview of the project after 1 year and the work of the scientific divers.

Keywords:
- water monitoring
- photogrammetry
- autonomous swimming robot
- artificial intelligence
- scientific diver

Introduction

Numerous dams, reservoirs and other inland waters in Germany and Saxony serve for drinking and process water, fishing, tourism and the ecological status. The last dry years 2018 and 2019 tested the function and security of supply of the water system. The growing number of flooded post mining lakes also cases significant challenges for their sustainable use due to recurring acidification processes. Previous water monitoring is done with a high level of personnel expenditure and the associated costs at regular time intervals. The projects RoBiMo (robot-assisted inland water monitoring) with the partner project AIRGEMM (Artificial Intelligence and Robotics for Geo Environmental Modelling and Monitoring) at the Technical University Bergakademie Freiberg want to contribute to a significant improvement of the water management and to reduce previous restrictions of the frequency and to provide assistance to overcome the intensity of the monitoring services. All the process is done in the context of global change and a better way of use.

Project goal und structure

RoBiMo combines six different institutes and five different disciplines. Part of the project are the institute for sensor materials, the institute for thermal engineering and technical thermodynamics, the interdisciplinary ecological centre, the chair for hydrogeology and hydrochemistry, the institute for informatics und the scientific diving centre. The project started in January 2020 und has a duration of three years.

The main aim is to improve the fresh water monitoring of dams and new lakes. These are like in the introduction named a big part of Saxony and become of greater importance due to the flooding of disused opencast mines and changing environmental conditions because of the climate change.

The main idea of the project is shown by **Fig.1**. An automatically controlled swimming robot, which is equipped with a high-resolution sonar and a multi-parameter sensor chain, is to be used to measure inland waters completely and with a resolution of the depth. In addition, not only the water subsoil but also the deeply resolved water parameters should be measured online. These data are visualized online and processed using artificial intelligence for virtual reality and a just-in-time display at the edge of the water. In addition to the depth-resolved water parameters, temperature, conductivity and turbidity, the outgassing and respiration of greenhouse gases and the influence of ground water flows should be investigated. For this purpose, a gas measurement on the water surface is to be carried out stationary with the swimming robot.

The obstacle detection is realized by the sonar system during the autonomous journey and used for the path planning. Communication takes place between the swimming robot and a base station, which is the interface for the user.

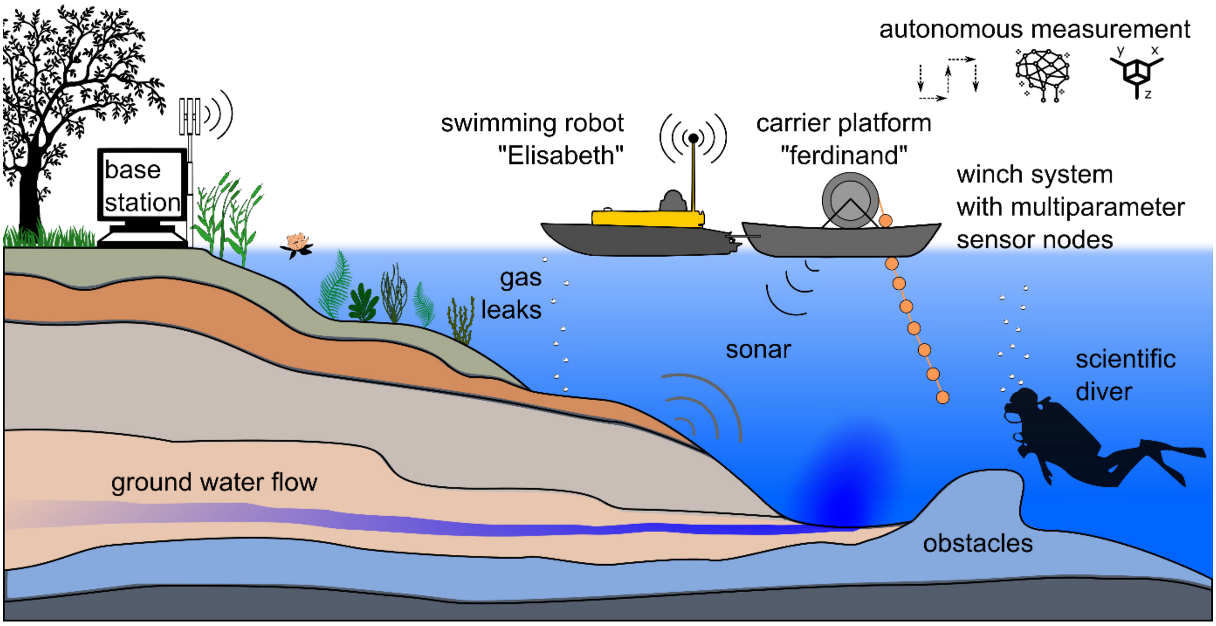

Fig.1. Schematic representation of the investigations with the swimming robot "Elisabeth" and the platform “Ferdinand” with an autonomous, three-dimensional, multisensory recording of inland waters, the detection of groundwater ingress, measurement of water respiration, validation of the results by scientific divers and presentation of the results using methods of artificial intelligence (Jarosch et al. 2020)

At the project start an all in on platform with a measurement of the water parameter, the underwater bathymetry and the respiration should be developed. Because of the different boundary conditions of the different measurement tasks, it was decided to split the measurement program. The investigation was split in to three parts, the sonar sampling, the water parameter measurement and the respiration measurement.

Sonar sampling is used for the underwater bathymetry and obstacles. These cases can run with a higher speed of the swimming robot than the measurements and generate so the first results. These are the base for further investigations und provides a high-resolution map for the investigation with the sensor chain. It also helps the scientific divers to prepare their dives and locate the taken samples and in situ parameter.

For measurement of the water parameter, a maximum speed of 0.5 m/s of the swimming robot is expected. So, we have a reproducible flow around the sensor and not so much flow resistance. The first prototype of the sensor node develop by the institute of electronic and sensor materials includes the acceleration, water temperature, pressure, turbidity and conductivity. The next generation should also include further parameters like the pH-value or oxygen and use another shape for better flow performance.

The gas exhaustion measurement is done by the interdisciplinary ecological centre and needs up to 30 minutes on one local place to calculate the CO_2 and Methane concentration and equilibrium. So, it is possible to investigate the potential of greenhouse gases absorption or emission of a lake or dam.

For the whole investigation an additional simulation by artificial intelligence to react of errors and environmental influences, like wind or waves, is done by the institute of computer science. For the first tests, path planning and operations a Kingfisher Clear Path swimming robot is used. It includes an automated operation system and an autopilot. This system is light, easy to use and a plug and play solution. The sonar system is a multi-frequent system with 1024 beams called Sonic 2020. It can generate sonar and backscatter data at once and measures with frequencies between 200 – 400 kHz.

Because of the different measurement cases and the boundary conditions it is necessary to use a custom build swimming platform, called “Ferdinand”. It uses the same operation and control system like “Elisabeth” but offers a cluster load system and a better performance. Herewith, a higher load and speed and a better control of the system is possible.

a) **b)**

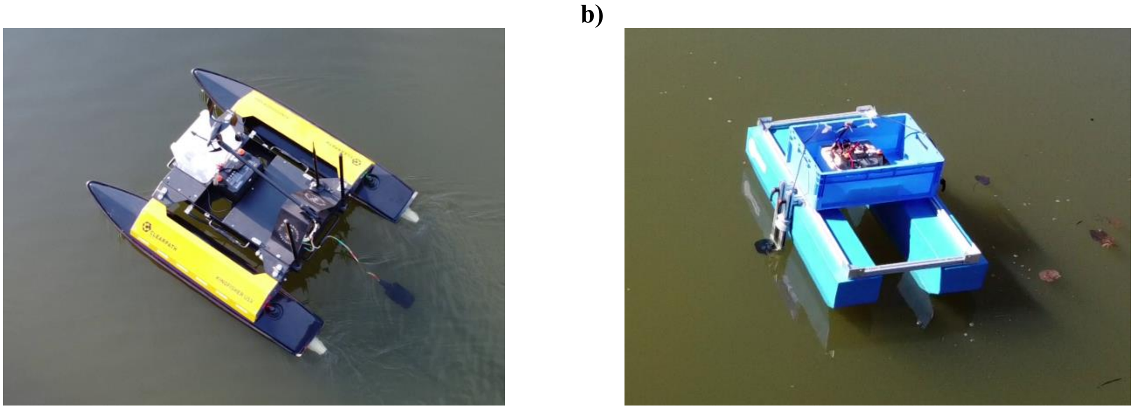

Fig.2 image of the two swimming robots “Elisabeth” a) and first prototype “Ferdinand” b) which are part of the project RoBiMo

The individual measuring systems can be exchanged on the platform by the frame. In the further it should be possible to use all three systems at the same time, thus enabling quick and effective measurement. The individual systems are currently being assembled and then tested with one platform. The validation is part of the 2021 measurement campaign.

The following part is limited to the measurement of the depth-resolved water parameters. A specific winch system has to be developed for the accommodate the sensor chain with the individual sensor nodes. This is done by the scientific diving centre. The functionality of the sensor elements and a reliable mounting must be taken into account, as well as a variable mounting of the sensor elements on the holder and guide rope. Furthermore, a space-saving storage and an effective positioning of the sensor nodes at depth must be observed during the measurement. For this purpose, the deflection of the sensor elements as a function of the speed as well as the basic weight must be considered. **Fig.2** shows the results as a function of speed. This deflection was calculated on the basis of a static system, taking into account the buoyancy and weight of the sensor elements as well as the basic weight and the speed-dependent drag force of the water.

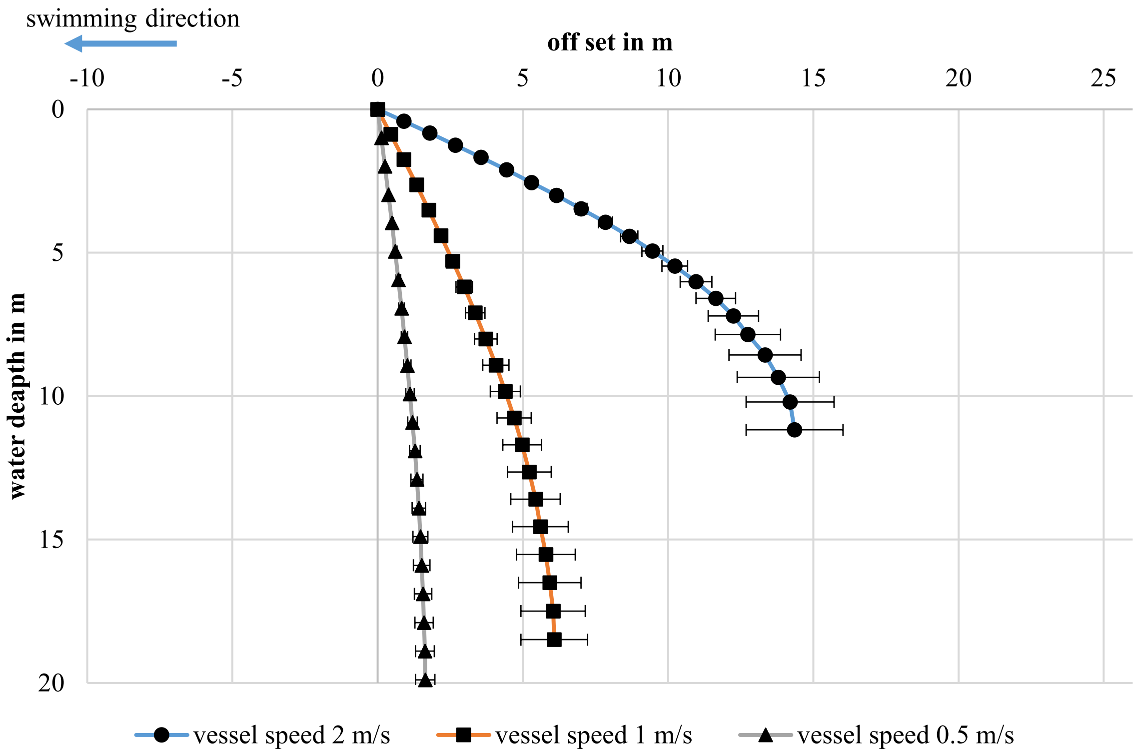

Fig.3. Drag of the sensor chain by the calculated vessel speed of 0.5, 1 and 2 m/s of a 20 m sensor chain with 20 sensor elements, an appr. 50N ground weigh and 5N sensor weight

This resulted in a speed of 0.5 m/s for a measurement of the water parameters. During the measurement, an exact depth determination by the pressure sensor and the acceleration sensor is planned.

Further tasks of the scientific diving centre are the validation of the measurement results. This is possible through a comparison with existing data, the measurement of in-situ parameters and the taking of samples, as well as a targeted manipulation of the sensors. For this purpose, depth profiles, e.g. temperature and conductivity, are recorded by the scientific divers and compared with the measuring system. The same can be achieved with further parameters in which water samples are taken from different depth layers and then examined in the laboratory by the Chair of Hydrogeology.

In addition to the water and sediment samples, samples are also required for artificial intelligence and the simulation of obstacles. For this purpose, three-dimensional point clouds and models are generated by the scientific diving centre with the help of photogrammetry. In this way, training data for the algorithms can be generated and the simulation environment can be prepared on real objects. An explanation of the photogrammetry process and some first results are given in the next chapter.

Photogrammetry process and results

The process of photogrammetry describes the reconstruction and calculation of three-dimensional objects on the basis of photos by means of a numerical triangulation of one and the same point from different directions. The methodical formulas and models are described in Agisoft LLC, 2021.

For scientific diving the photogrammetry has a lot of advantages. So it offers a better work plan and a better dive plan. With a first investigation dive it is possible to visualize an overview of large areas what can´t be seen by a diver at once. So, it is possible to show to all team members the points of interest, plan the dive depth and calculate your dive time. It is also possible to generate 2 or 3D grid for georeferenced maps. So locate sample points and points of interest can documented. Further, it is possible to compare and analyse large regions over a long period of time. It is also possible to calculate with the object and measure distances and volumes or use it for simulations. For the photogrammetry process the following steps of **Fig.4** are part of the calculation:

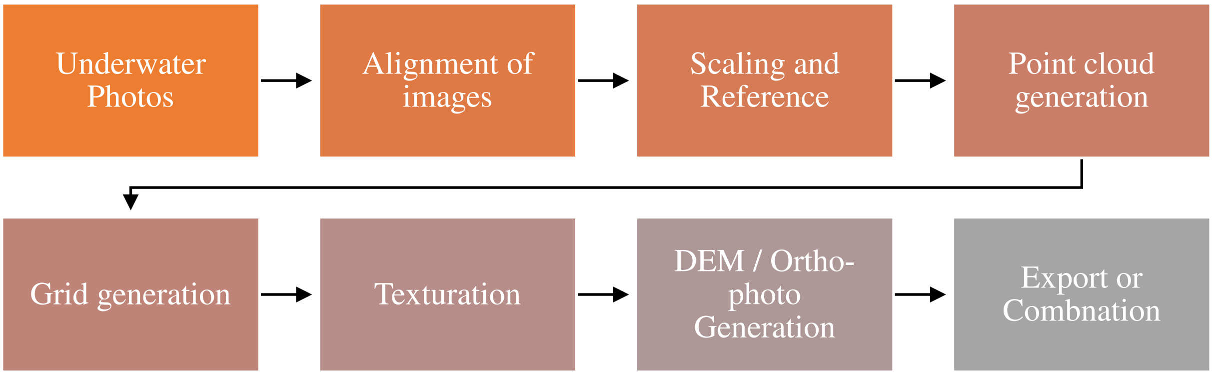

Fig.4. General process of the photogrammetry with an individual scaling process (Agisoft LLC, 2021)

For the start, the underwater photos are taken in a flodden quarry in Meissen, Saxony (51.16723°N, 13.49541°E). It is really essential to get qualitative good photos with light on the whole image to get a good result of the model. For the presented results a digital camera, Sony Alpha 6000, with an underwater case and two underwater lamps with 5.000 lm as video light are used. For the alignment of this object 145 photos with high accuracy were used. For the alignment more photos then theoretically necessary are used, to choose the proper photos and discard the before the the calculation. The result of the alignment is shown in **Fig.5** a).

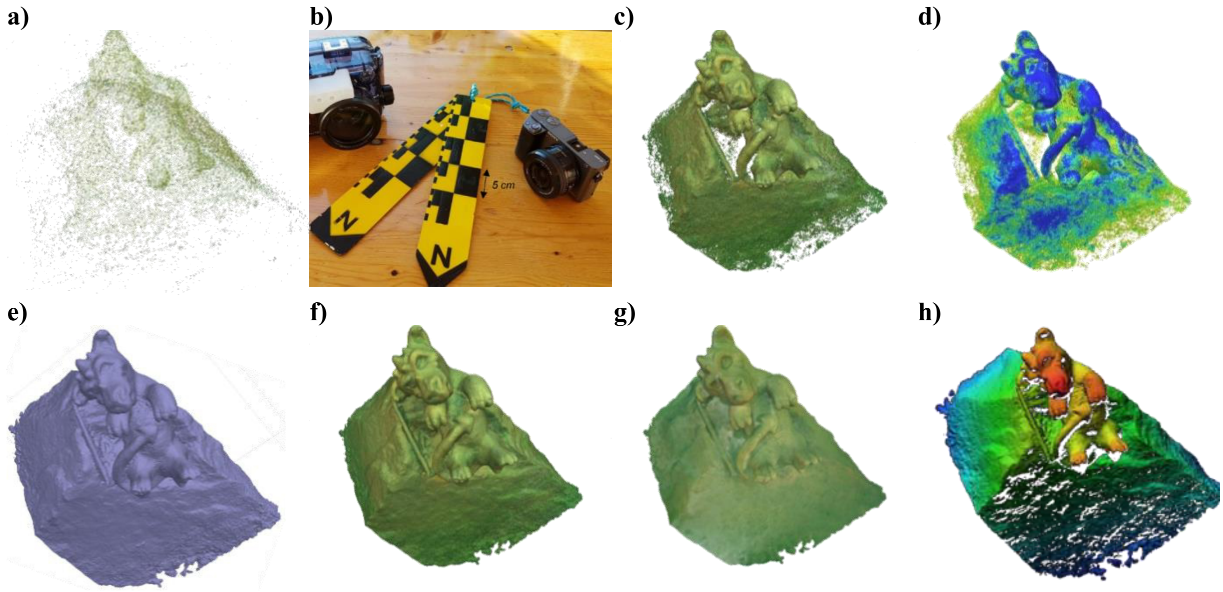

Fig.5. the photogrammetry process with the aligned images a), the scale and camera b), the coloured point cloud c), the confidence of the point cloud d), the reconstructed unstructured grid e), the coloured 3D-grid f), the textured model g) and the DEM-model h)

After that a scaling and reference process is necessary. For that every time of the photo process the scales, like **Fig.5** b) has to be part of the object. There you can measure at least 1 cm and rescale the object for a local reference system. With these markers it is also possible to use GPS coordinates.

With the result of the scaling process the depth maps und the point cloud are generated. These are shown in **Fig.5** c). For a better result the confidence index is calculated. It is an indicator for the number of depths maps at one point during the calculation process. For better results only points with a value of better than 3 are used. All other points are discarded and not part of the grid calculation.

The calculation is based on an unstructured triangle grid. With the reconstruct surface of the underwater object it is possible to measure and calculate distances, surface and volumes.

As mentioned in capture 2 the photogrammetry is used as trainings data for the artificial intelligence, the obstacle detection, object classification and separation. These is possible with the point clouds and the grid. For further investigations of the institute of computer science, use the generated point clouds. (Reitmann et al. 2021)

For a better visualisation, the texture of the object can be calculated. With that, the images are projected to the 3d-grid to get much more realistic objects. For further investigations a DEM-Models and orthoreflected photos can generated and used as 2D-Maps for bigger areas. There you can see the different levels of the object. In combination with an underwater bathymetry, you can get the orientation of the object on the ground. For the shown object, the whole reconstruction process takes 219 minutes on a numerical workstation. For the reconstruction process a full script based calculation on a high performance cluster system of the TU Bergakademie Freiberg is done.

The last step of the working process is to combine or export the models and point clouds to nearly every modern system you want. Objects can be shown as 3D-PDF, .obj, .stl, .ply or Image-File. Henceforth, you can share the models with all scientists. For the whole process the software Agisoft Metashape 1.7.0 is used. The parameters used for the reconstruction are shown in the **Table 1**.

Table 1. reconstruction parameter for the object 0,6 x 0,5 m dragon of the quarry in Meissen, Saxony

Photogrammetry Steps	Reconstruction parameter	Results	Calculation time
Alignment	High	145 of 145 photos 83.934 points	7 min 33 sec
Depths Map	High quality Mild filtering	145 depths maps	107 min 00sec
Point cloud	High quality Mild filtering	6.561.606 points	40 min 41 sec
Mesh	High faces	2.955.035 faces	4 min 03 sec
Texturation	Mosaic; Ghosting filter enable; hole filling enable	4,048 x 4,048 x 4, 4 channels,	15 min 39 sec
DEM	Source: Mesh	2802 x2554 pixel	06 sec
Orthophoto reconstruction	Source: Mesh	5292 x4120 pixel	6 min 14 sec
	Summary:	**Resolution:** 0.000869 m/pix **Point density:** 1.320.000. points/m²	181 min 16 sec

For the further investigations in the project RoBiMo a process for the combination of the photogrammetry object and the generated sonar point cloud will be developed and tested.

Conclusion

In the course of the investigation of the RoBiMo project, it has been shown that a complete combined investigation of the water bathymetry, the depth-resolved water parameters and the measurement of the respiration parameters is not possible. Therefore, 3 different measurement cases were developed, which can be carried out with a time delay as well as synchronously. This allowed the expected examination time to be shortened and a more flexible examination with coordinated measurement periods to take place.

The swimming robot intended for use, "Elisabeth", was prepared and tested by the Institute for computer science for the autonomous path planning. In the course of the project, however, it became apparent that the necessary flexibility and load capacity were not available. So, a new swimming platform "Ferdinand" was designed. This has the advantage of flexible loading and complete customized construction.

For the tasks of the SDC, an in-situ check and a comparison of the measured parameters with water samples were carried out. Furthermore, training data of the water structure are generated by means of photogrammetry. In this way, the algorithms for point classification can be tested on real objects. The photogrammetry process can be structured in the alignment, the depth map generation, point cloud calculation, meshing, texturation and evaluation. For that a numerical workstation or the high-performance cluster system of the TU Bergakademie Freiberg is used.

The photogrammetry process offers a big opportunity not only in scientific work. It is possible to transfer the unknown magic of the underwater world to all people, not only the divers. In addition, the data can be used for a better diving training, a better preparation for beginners and a new step of safety for the orientation in unknown areas. For science it offers the opportunity to investigate all details by specialists after the dive and with high resolution.

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