RiverCloud – A Multi-sensor UAV/USV Tandem System for High Resolution Data Acquisition of Water Bodies

Ralf BECKER, Benjamin EBERHARDT, Christoph EFFKEMANN, Thomas GATTUNG, Issa HANSEN, Louis MAKIELLO, Enrico NEUMANN, Juan RAMIREZ, Raimund SCHWERMANN, Julian TEEGE und Jörg BLANKENBACH, Germany

Key words: USV, tandem, waterways, sensor fusion, georeferencing

SUMMARY

In light of increasing urbanization and climate change waterways are already of outstanding importance for the national and international exchange of goods. The development and maintenance of waterways therefore represent challenges for the future, which must be carried out in the European Union in accordance with the EU Water Framework Directive and the EU Floods Directive, among others.
The required geometric and semantic data with spatial reference (geodata), however, are currently not available with sufficient consistency, spatial and temporal resolution, area coverage and/or accuracy. However, increasing digitization and the associated possibilities for data collection and provision now allow improved access to information, which simplifies the balancing of diverse, sometimes conflicting interests. At the same time, the possibilities of data acquisition with regard to sensors and carrier systems have evolved significantly in recent years. These include more powerful scanning and imaging sensors as well as unmanned aerial vehicles (UAV) and unmanned surface vehicles (USV).
The goal of the mFund project RiverCloud, funded by the German Federal Ministry for Digital and Transport (BMDV), is to develop an autonomous and networked UAV/USV tandem system as a basis for the holistic acquisition and provision of spatially and temporally highly resolved data for the development and maintenance of waterways and to support waterway management. The collected data shall be analyzed by combining them with existing macro-scale data (e.g. from sounding vessels) and the results shall be integrated into the models and workflows of the users from the water management sector.
The article first describes the objectives of RiverCloud with regard to the overall system, the used carrier platforms, and the employed sensor technology. An essential challenge is the precise georeferencing of all acquired data in a uniform coordinate system. Therefore, one of the key points of the project is the development of a method for the best possible determination of the position and orientation (pose) of the autonomous UAV/USV tandem system based on various sensors. In addition, results and data from a survey campaign are shown. Finally, the RiverCloud data provisioning strategy and the RiverCloud web portal are outlined.

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1. INTRODUCTION

Waterways are of high relevance for the national and international exchange of goods. Due to increasing urbanization and the resulting congestion of road space, the expansion and maintenance of waterways (e.g., ensuring fairway depth) are challenges of the future, among other things against the background of climate change (low water). Expansion and maintenance must be carried out in the European Union in accordance with the EU Water Framework Directive and the EU Floods Directive, for instance, in order to make the planning and implementation processes safe, future-oriented and efficient despite the divergent objectives of use as a transport route and environmental protection. In order to answer the complex questions associated with these processes in sufficient quality, consistent as well as spatially and temporally highly resolved geometric and semantic data with spatial reference (geodata) of the most varied kind (e.g. water quality, vegetation structure, underwater/overwater structure geometry, water body topography) are required.
With advancing digitalization, the data required for various applications in water management are increasingly available. A wide variety of sensors, e.g., remote sensing with satellites, sensors such as cameras or laser scanners attached to manned aircrafts/helicopters or unmanned aerial vehicles (UAV), are used for data capturing. However, they do not have the required temporal and spatial resolution, coverage and/or accuracy for many issues. For example, the sole use of UAVs is not expedient for watercourse management, as the aerial recording of watercourse topography is only possible with the required accuracy to a very limited extent. Moreover, the water topography data usually collected with sounding ships also do not capture the entire flow cross section (shallow water and groyne areas as well as backwaters and oxbow lakes cannot be reached), the setup times are long and the use is expensive.
For shallow waters and areas that are difficult to access, small, maneuverable unmanned surface vehicles (USV) with low draught offer a possible solution compared to manned direction-finding ships. Equipped with the appropriate acquisition sensors, they can be steered sufficiently close to the target locations and thus provide the desired data with the scenario specific required accuracy and resolution. However, in some areas the necessary sky clearance to ensure georeferencing with sufficient accuracy and without gaps by means of Global Navigation Satellite System (GNSS) mounted on the USV is not given– for example due to existing vegetation or constructions. One possible approach to bridge these GNSS-less and, thus, position-less areas is to fuse various sensors (e.g. Inertial Measurement Unit (IMU),

camera) in combination with advanced positioning techniques (e.g. Simultaneous Localization and Mapping (SLAM)).
In this paper, the multi-sensor USV/UAS tandem system currently being developed is introduced. First, in section 2 the underlying research project RiverCloud is outlined. In section 3 the main hardware including the added sensors and the software components as well as calibration aspects are described. Section 4 is dedicated to the multi-sensor fusion strategy for precise boat navigation as well as for georeferencing of the water body data acquired with the tandem system. Section 5 provides selected results of first practical tests. Finally, in section 6 the system architecture for data provision is described.

2. PROJECT RIVERCLOUD

In the research project RiverCloud funded by the German Federal Ministry for Digital and Transport (BMDV), a consortium of partners from science, industry and public administration is developing a novel, unmanned and coupled tandem waterway data capturing system consisting of an USV (survey boat) and an UAV (drone). Starting from the central measuring system as a basis (WP1), the project is divided into the work packages data acquisition/processing (WP2), applications (WP3) and provision of data (WP4) (Fig. 1).

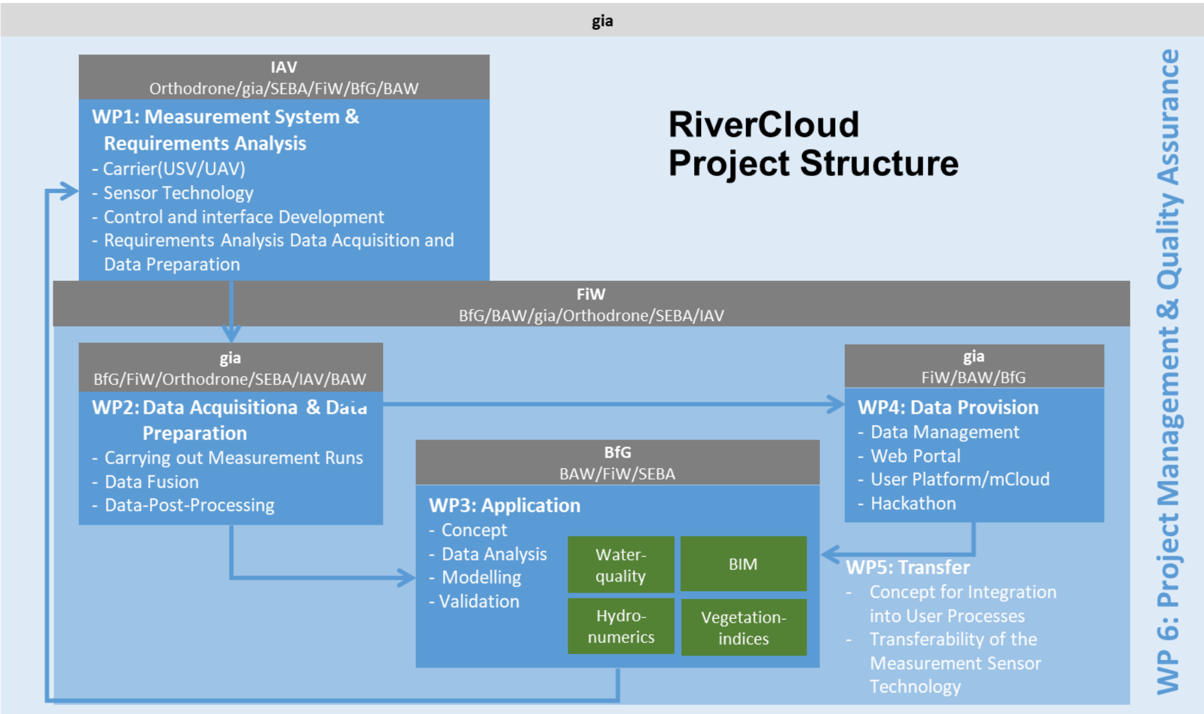

Fig. 1: RiverCloud project structure with the distribution of tasks among the project partners involved.

The RiverCloud tandem system is to be used for monitoring and management of waterways and their environment (wetland areas, vegetation, etc.) under economic and ecological aspects. For this purpose, RiverCloud is based on a multi-sensor technology in order to acquire spatially and temporally high resolution, georeferenced geometric and semantic data for a variety of hydraulic engineering and water management tasks. The main data products are the description of the surface and subsurface topography of shallow waters and their adjacent riparian stripes, information on the biological-chemical properties of the water body through various water quality parameters (temperature, salinity, pH, etc.) and hydrodynamic data on flow velocities over the entire water body cross-section. RGB and near infrared (NIR) image data on the riparian stripes and hydraulic structures contributed by various cameras on UAV and USV as single video or panoramic images and their sub-sequent products such as image-based point clouds complement the data.

By using a compact survey boat with a low draught, RiverCloud aims to focus on shallow water areas, the surroundings of oxbows, tributaries and groynes –especially their interstices – as well as water body areas with high sediment dynamics. This is because these rather small-scale areas of application can only be served inadequately, both technically and in terms of time, with the conventional sounding vessels of the water management administration. The data obtained by the RiverCloud system can be used to improve hydrodynamic-numerical models of waterways and to carry out holistic analyses of the vegetation structure in the waterway environment. For hydraulic structures such as locks and weirs, RiverCloud provides the geometric data for the creation of digital as-is structure models, which later form the basis for Building Information Model (BIM)-based maintenance and control. In the project, BIM modeling will be investigated on the basis of the various captured data (images, pointclouds derived from the images as well as MBES data). The aim is to assess whether and how well BIM modelling is possible using this data.

The spatially and temporally referenced data of the water bodies, the water body environment and the structures are made available to a broad user group as raw and refined Open Data products in the Mobilithek of the BMDV (BMDV 2021). The basis for the data provision is a (geo)database system as a powerful data storage component of spatio-temporal data. In RiverCloud, a web portal for the GIS-based dissemination of waterway and construction data with the corresponding geo web services is being implemented.

3. CARRIER SYSTEMS AND SENSORS

The RiverCloud tandem system is composed of the USV on the water side and a UAV on the air side as carrier vehicles, which are equipped with diverse sensor technology for position and orientation (pose) determination and data acquisition. The most important components and features of carrier vehicles and multi-sensor technology are described below.

3.1 Survey boat (USV)

The unmanned REAV-16 from HydroSurv Unmanned Survey Ltd (HydroSurv 2022) serves as the survey boat or USV, (Fig. 2). The 1.60 m x 1.20 m (L x W) catamaran design with symmetrical polyethylene hulls can be completely dismantled if necessary and is designed for two-man survey teams. The regular draught of 40 cm has been reduced to approximately 25 cm by special adjustments to the propulsion system for the RiverCloud project. The purely battery-powered propulsion system uses two height- and angle-adjustable Torqueedo electric outboard motors, which are individually controllable when mounted on the hulls. Two sets of motors are available for RiverCloud, each rated at 0.4 kW and 1.1 kW, respectively. The boat is characterized by high maneuverability and precise low-speed running. The hydrostatically optimized design is said to ensure high stability even in moving water. Two drive batteries with 0.9 kWh each allow measurement campaigns up to 8 h. On board within one of the hull bodies is a Windows-based, fixed industrial PC with an Intel i7 processor, 32 GB RAM and SSD hard drive, through which the primary data recording and communication with the control station are realized. Remote control during a survey campaign works either manually with a laptop using the Remote Control Workstation (RCW) software package or in autopilot mode with waypoint planning. The data connection between the outstation (usually on the shore) and the USV is done with antennas via (Long Range) WiFi or – for longer distances – via a 4G/LTE mobile data connection. In addition, the boat can also be maneuvered manually via a commercially available radio remote control.

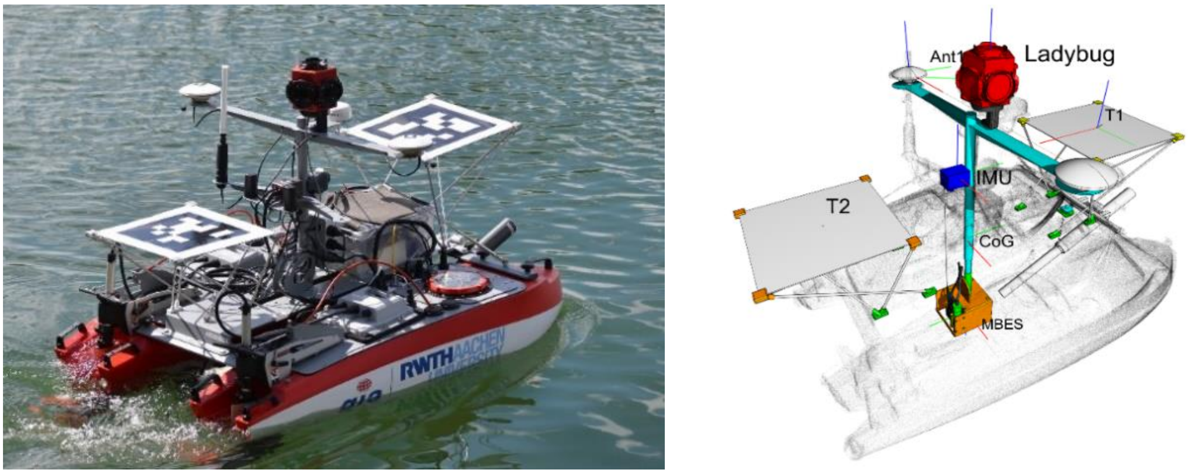

Fig. 2: RiverCloud USV during a measurement run (left) and sensor arrangement (right, with sensor coordinate systems).

The REAV-16 has a factory-fitted mast (which can be folded down for transport) attached to the bridge structure via an adjustable, folded aluminum beam that is used to support the various sensors for navigation and data acquisition (Fig. 2). Above water, the mast structure supports a Novatel CPT7 GNSS/IMU positioning system (Novatel 2022) with two antennas. This SAPOS RTK-capable unit forms the basis for determining 1 to 3 cm accurate USV trajectory or pose during a survey cruise. The USV's pose determination relies heavily on this GNSS sensor technology. Among other data, the IMU data will be used for bridging GNSS signal gaps. For the RiverCloud targets, a Ladybug 5 camera (Ladybug 2022) was additionally installed on the USV mast, which has a dual function in this context. First, similar to a previous research project, the omnidirectional multi-camera system serves to optically capture the overwater area in the form of RGB images (Effkemann et al. 2017). The six-part image sets are processed into 360° panoramas for visual inspection tasks in post-processing, which are also used to derive image-based point clouds using Structure from Motion (SfM) (Szeliski 2011, Prince 2012) to reflect the three-dimensional geometry of the water environment, an important data outcome. Second,

the project will investigate whether the Ladybug camera is suitable as an additional location technology by using visual odometry, visual inertial odometry or visual SLAM (V-SLAM) (Yousif et al. 2015) methods respectively. Besides the ladybug camera, a seperated stereo camera system was set up for this purpose to evaluate both options. The methods of fusing these multisensory observational data for precise postion calculation of the USV (and the captured data) will be discussed in more detail in section 4.
Underwater, at the other end of the mast, is a multibeam echo sounder (MBES (Sonic2020 2022)), e.g., for detecting structures underwater (Fig. 3, left). In addition to the vertical orientation, the MBES can optionally be tilted in various angular increments transverse to the direction of travel, e.g. in order to capture data in shore-near, shallow areas. The MBES otherwise captures the topography of the water bottom with an accuracy of better than 10 cm as a basis for a Digital Terrain Model – Water (DTM-W). The operation of the MBES, the capturing and processing of the echo sounder data are carried out via the USV on-board computer with the software packages Quinsy and Quimera (Qps 2022).

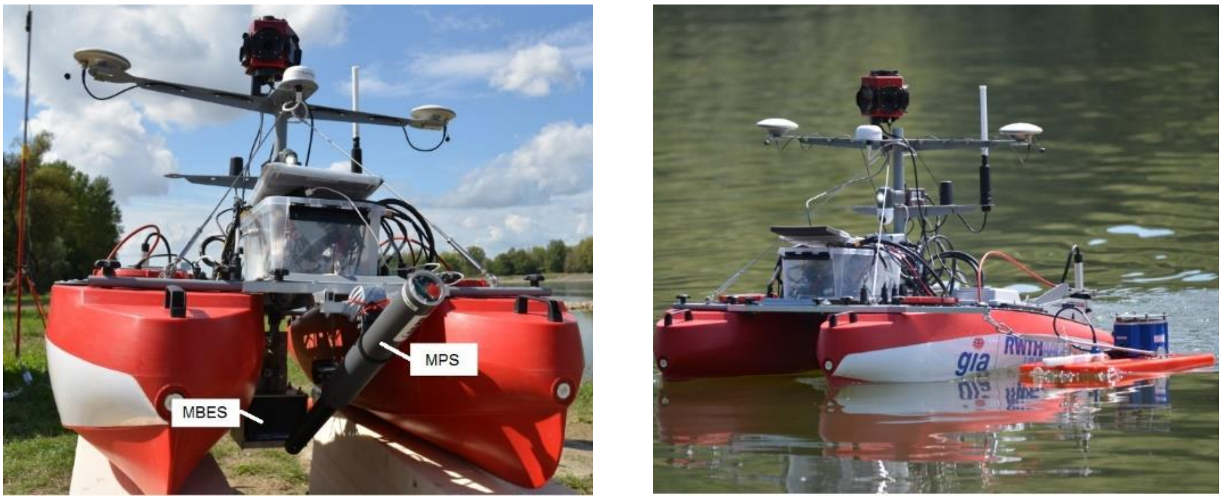

Fig. 3: USV with multibeam Echosounder (MBES) and Multiparam Etersonde (MPS) (left); Acoustic Doppler Current (ADCP) in the tow rope of the USV (right)

Optionally, a multiparameter probe from the industrial project partner SEBA will be installed in the front center of the boat to register various water quality parameters such as temperature, conductivity, O2 content and saturation, pH or turbidity in a self-contained memory of the probe along the USV trajectory. For the measurement of flow velocities along the water cross-section, an optional Acoustic Doppler Current Profiler (ADCP) (Fig. 3, right) can be carried on the side of the boat, which, like the MPS, operates as a stand-alone system and thus does not require the resources of the USV electronics. Completing the boat sensor system are two markers (target markers) approximately 50 cm in size that serve as an optical link between the USV on the water and the UAV in the air (Fig. 2 T1 and T2).

3.2 Drone (UAV)

A key feature of the tandem system is the navigation and control of the camera-carrying UAV, which autonomously follows the primary guiding USV based on the markers. Conversely, however, the data from tracking the USV also helps to improve the survey boat pose For this purpose, a follow-me tracking mode is implemented based on the analysis of images from a tracking camera carried by the UAV. The tracking accuracy was investigated in simulations, according to which an accuracy of better than 10 cm can be assumed. The tracking camera used on the UAV is a monochrome Ximea MX124MG-SY (12 MP) (Ximea 2022) with a 16 mm lens. In addition to pose determination and tracking of the UAV, the camera is also utilized to measure the surface flow velocity of the water body by Surface Structure Image Velocimetry (SSIV (Pearce et al. 2020)). This method can be used to determine discharge hydrographs, flow velocities, and water levels using numerical image processing algorithms based solely on video images, i.e., without applying tracers in the water.
The used UAV is an Avartek Boxer Hybrid heavy-lift drone (Fig. 4) contributed to the project by the industrual partner Orthodrone. The diagonally approximately 1.5 m tall, gasoline-powered quadrocopter has an empty weight of 17 kg and can be in the air for several hours without interruption, depending on payload (up to 6 kg) and refueling (max. 7 liters). The flight propellers are powered electrically by an on-board generator. Typical flight altitudes in the RiverCloud project are 30 to 50 m.

Fig. 4: Avartek Boxer Hybrid drone (Source: Avartek 2022)

The drone is basically used as a carrier system of three sensor packages for different mission or application scenarios. In the standard case – in addition to the Ximea tracking camera – the UAV is equipped with a PhaseOne iXM-MV100 camera (PhaseOne 2022) with 35 mm lens for classic RGB images, which form the basis for photogrammetric analyses as well as the generation of image-based point clouds. Typical results are DTM data of overwater topography and ortho images as well as three-dimensional acquisition of riparian vegetation or hydraulic structures. The camera is mounted on the UAV using a Gremsy gimbal, with a choice of vertical or oblique images. Together with the RGB camera, a PhaseOne camera with NIR sensor for infrared images is mounted to the UAV in a second application scenario. These images are used, for example, as the data basis for vegetation studies. Finally, in the third use case, the UAV is equipped with the bathymetric LiDAR sensor BDF-1 (Riegl 2022). The scanner uses green laser light and the vertical measurement beam provides results down to 1.5 Secchi depths. Because of the weight of the BDF-1 (~5 kg) only flights without one of the above-mentioned cameras are possible then. The bathymetric scanner is used to capture the shallow areas of the water change zones that are inaccessible to the MBES and thus complements the RiverCloud database mainly underwater for deriving consistent surface models (DTM/DTM-W).

3.3 Adjustment and Calibration of the USV Sensors

As described above, the Novatel CPT7 GNSS/IMU unit with two antennas, the MBES echo sounder, the Ladybug camera and two markers are located on the USV as sensors for position determination and USV-side data acquisition (see Fig. 2). For the multi-sensor fusion (see section 4) and the error-free georeferencing of the captured data, the position of the sensors and target markers among each other must be known, i.e., the sensor ensemble must be calibrated. For this purpose, the translational position of all sensors and targets (lever arm) has been determined relative to a central USV coordinate system (body system) – and thus indirectly among each other. For the panoramic camera and the MBES, the rotation angles (misalignment) had to be determined additionally. The origin of the local vessel coordinate system is arbitrary. It could be in the center of one GNSS antenna or in the center of the IMU – we have chosen the Center of Gravity (CoG) because it is usually the origin for all calculations. The best position of the IMU would be close to the MBES, but that is not possible in our case since the cable connectors of our GNNS/IMU system are not water resistant. Thus, the central body system was defined in such a way that the origin is located approximately in the CoG and the axes are parallel to the boat or IMU (Fig. 2 right). The sensor positions have been measured geodetically using the respective body corners and edges utilizing a high-precision robotic total station with a standard deviation of 0.4 mm. For the measurement of the edges, corners and sphere prisms with magnetic sphere bases were used. The rotational position of the sensors could be determined by averaging the angles of the housing edges. For the Ladybug panoramic camera, the relative positions and rotations as well as the distortion parameters of the five individual cameras are already stored in the panoramic camera firmware. The accuracy of the interior orientation is the equivalent of 2 mm at a distance of 10 m or 0.0116 degrees (Flir 2022).
All sensors are mounted on a mast, and the relative rotation angles are not absolutely constant. Due to mechanical stress, the rotation angles may change by a few tenths of a degree over time. For example, in the case of overlapping MBES measurements in two opposite directions, an incorrect roll angle will have the effect of creating a gap in the profile transverse to the direction of travel. The installation angles of the MBES are therefore corrected at the beginning of a survey campaign with a so-called patch test, in which corresponding calibration runs are carried out with the USV according to the manufacturer's instructions. The three angles Roll, Pitch and Yaw are corrected in post-processing with the aid of the QPS Qimera software until the gaps between the profiles have disappeared or are minimized.

4. MULTI-SENSOR FUSION

In the target areas of the RiverCloud project, near structures (e.g., inside a lock, under bridges) or high riparian vegetation (e.g., under trees in oxbow lakes), GNSS reception is insufficient for accurate pose determination of the USV. The fusion of different sensors and positioning sources promises improvement, namely, in addition to GNSS, the use of IMU, camera images using the method of V-SLAM, and tracking with camera image data from the accompanying UAV (Fig. 5, left).

The goal is to fuse the subsystems into an optimal overall solution using stochastic methods for state estimation of dynamic systems (e.g., Kalman filter (Kalman 1960)). The USV's Ladybug 5 omnidirectional camera system (panoramic camera) was initially to be used for the monocular V-SLAM method. The disadvantage of this approach was that the scale must be estimated dynamically which turned out to be a potential weak point. Thus, in the extended approach an additional camera system (consisting of two CMOS MT9V022 sensors (Utronics 2022)) with different baselines (20 cm, 40 cm, 1.0 m) has been set up to investigate a stereoscopic V-SLAM method (Fig. 5, right). This requires additional hardware, but the scale does not have to be estimated dynamically and is known through the fixed basis of the stereo system.

For the algorithmic implementation, the Robot Operating System (ROS) (ROS 2022) lends itself. The use of an ROS network facilitates the implementation, modification and testing of various existing algorithms. In the absence of the UAV, the pose estimation of the USV is performed using "Robot Localization" (Moore & Stouch 2014) and "ORB-SLAM3" (Campos 2020). In the presence of the UAV, a marker detection algorithm based on AprilTag (Wang & Olsen 2022) is also used.

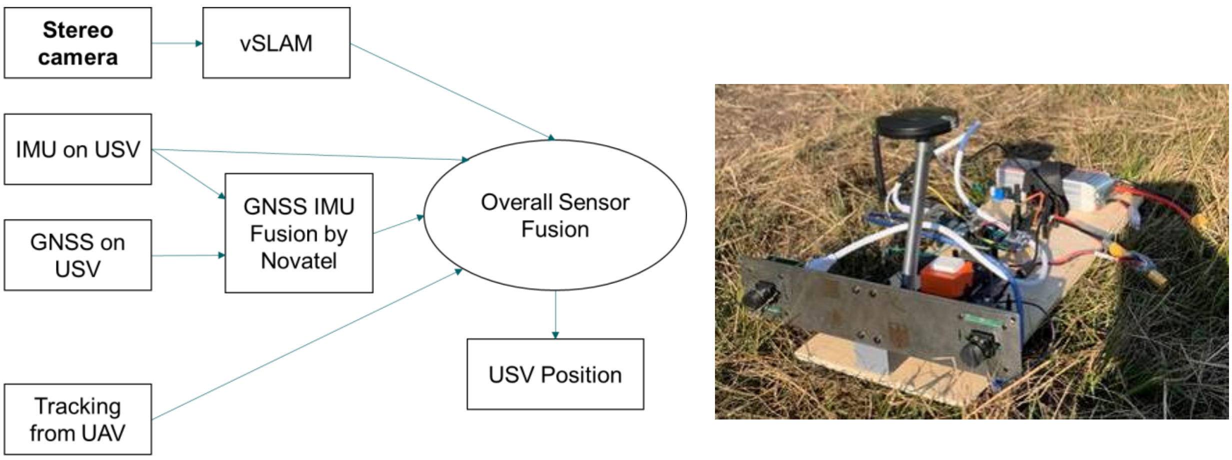

Fig. 5: Overall structure of the pose estimation approach (left) and V-SLAM stereo camera system with 20 cm baseline (right)

The robotic localization package includes an implementation of an Extended Kalman filter (EKF) (Bishop & Welch 2001). This package can be used to fuse an unlimited number of inputs from multiple sensors. It supports inputs for position, orientation, linear velocity, angular velocity, and linear acceleration. The output of the package is an estimate of the vehicles position, orientation, velocity, and angular velocity.

In our case, we input the pose estimates from the GNSS/IMU system, the V-SLAM algorithm, and later also from UAV tracking. Therefore each method (GNSS/IMU, V-SLAM, UAV tracking) provides its own pose information together with a precision measure (e.g. standard

deviation). Each of these positioning estimates may be a result of its own EKF (e.g. GNSS/IMU solution) or a specific calculation procedure (e.g. UAV tracking). The V-SLAM poses are converted to translational and rotational velocities in the vehicle reference frame before being used as the measured value in the EKF. The raw acceleration (including gravity) from the IMU in the Novatel CPT7 system and the filtered acceleration can be used in the filter. It is obvious that all input data of EKF must be in the same coordinate reference system. Otherwise, corresponding transformations must be carried out. The different pose determination calculations with their precision measures are fused into the combining EKF, yielding the final best-fit position.
Currently test drives against ground truth data, first on land, later on water, are carried out for system evaluation and findig the best configuration of the stereo camera system which includes among others camera settings, parameters for image analysis, the evaluation of lenses with different focal lengths (including 6 mm and 2.8 mm) and different baselines between the two cameras (including 10 cm, 20 cm, and 1 m). In the current testing and development phase, we use GNSS or total station tracking as ground truth to assess the accuracy of V-SLAM and UAV tracking. The test runs are carried out in well-defined test areas to improve our developments through repeated testing.

5. TEST RESULTS

Although the hard- and software development is not yet complete, some test surveys have already been carried out.
One of the study sites is the island ”Niederwerth” in the river Rhine near the city of Koblenz, Germany. The island splits the Rhine into the main channel and a side channel, the ”Vallendarer Nebenarm” where reduced flow velocity was suited to test the stability and maneuverability of the USV on a federal waterway. The near-natural riparian vegetation in the southern part of the island allows to analyse vegetational structure parameters defined in WP1. Furthermore, high resolution reference point cloud data for this site is available to assess data quality of the used sensors. In July 2022, therefore, an evaluation of the tandem system was carried out, i.e. data was collected both from the water using the USV and from the air with the UAV. Due to open sky conditions, navigation and georeferencing of the USV could be accomplished using pose estimations supplied by the Novatel GNSS/IMU system.
The nadir-view captured images of the UAV have been used for point cloud generation through a SfM workflow. The flight plan was designed to achieve a ground sampling distance of 0.5 cm/pix with focus on the canopy. With this, derivation of a canopy height model (CHM), individual tree detection, tree crown delineation and aboveground biomass calculation will be tested and assessed. For assessment ground truth data was captured at the study site. Typically, SfM-generated pointclouds from nadir-view images lack vertical information where overhanging structures, such as canopies, prevail. To enhance point density in lower stories of the riverbank vegetation the data of the USV camera (Ladybug 5) was used to acquire image data for point cloud generation while maneuvering close to the riverbank for higher image resolution with respect to the vegetation. The resulting point cloud (Fig. 6) shows the potential to capture vertical vegetation structure.

Fig. 6: Point cloud derived from Ladybug 5 imagery. Shows riverbank and adjacent vegetation.

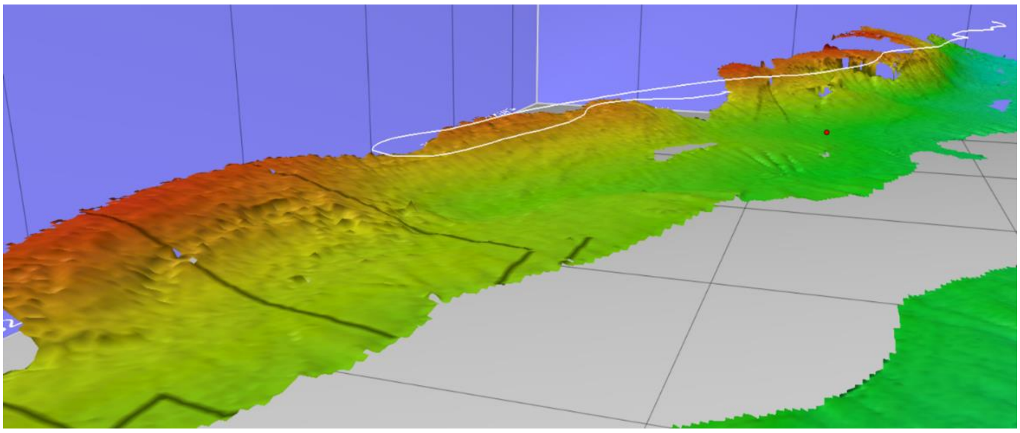

Fig. 7: MBES-Daten Niederwerth: 3D view of the filtered point cloud, MBES tilted at a 30° angle

The MBES survey was designed to capture shallow subwater topography where standard capture methods are not able to reach. To maximise the capture area in the most shallow part the MBES was tilted at a 30° angle for the nearest riverbank track and reverted to nadir view for the rest of the survey. Like this, shallow areas, which are not reachable by conventional administrative sounding vessels, could be captured (Fig. 7) and show potential to enhace and densify the DTM-W.

For combining various data sources as well as already existing data in the target reference systems, possibly different coordinate systems must be taken into account. All calculations, in case of sensor fusion (section 4) or in software like Quinsy, are done in WGS84 coordinates. The software used (e.g. Quinsy) allows a variety of different coordinate reference systems (e.g. ETRS89/UTM) to be selected for export, so that the resulting data can be linked to any other third-party data. The needed transformation will be done during the export process.

In further project steps, we will evaluate the qualitiy of the captured data by comparing to ground truth data or complementary captured data, e.g. comparing bathymetric LIDAR and MBES data in the overlapping shallow water zones.

6. DATA PROVISION

The framework of the research project envisages from the outset that all collected and processed data will be made publicly available. For this purpose, the funding ministry has set up the so-called Mobilithek[1], a data portal that is accessible online for everyone. The data can be accessed via file download or data interfaces like web services. Metadata (title, description, category) make it easier for users to find relevant data.

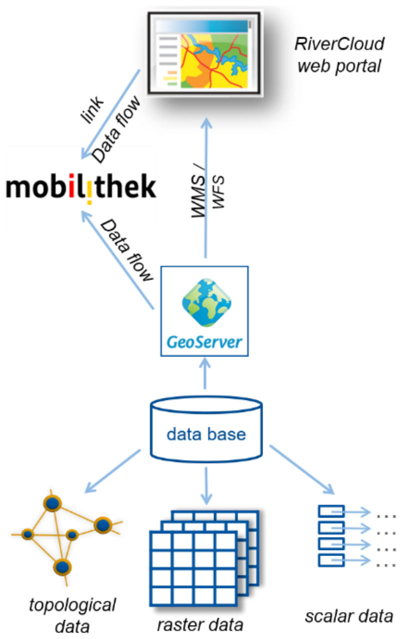

Fig. 8: RiverCloud data provisioning strategy

The RiverCloud project generates data with a wide variety of types (topological, raster, scalar). This data is stored in the project database and, depending on the data type, made accessible via suitable interfaces such as ftp download of file-based formats (e.g. CSV) or by open geo web services e.g. Web Map Services (WMS) / Web Feature Services (WFS) of the Open Geopspatial Consortium (OGC) (Fig. 8). For the latter, a geo web server has been set up providing the needed geo web services. For access, the RiverCloud web portal will be linked in the Mobilithek. Information about the type and content of the data is given via the metadata mentioned above.
In the web portal (Fig. 9), the available data can be selected and viewed in a georeferenced way. Depending on the data type, it can be accessed by selecting and retrieving the desired data as a download or by using the geo web services provided by the portal.
Captured data and derived products are heterogenous due to the various sensors and phenomena. Thus, various data types and formats are used. However, as mentioned above when implementing the web portal we consider open standards (e.g. WMS, WFS) as far as possible

[1] https://bmdv.bund.de/SharedDocs/EN/Articles/DG/mobilithek.html

that allow interoperability in accordance with spatial data infrastructure initiatives (e.g. INSPIRE directive).

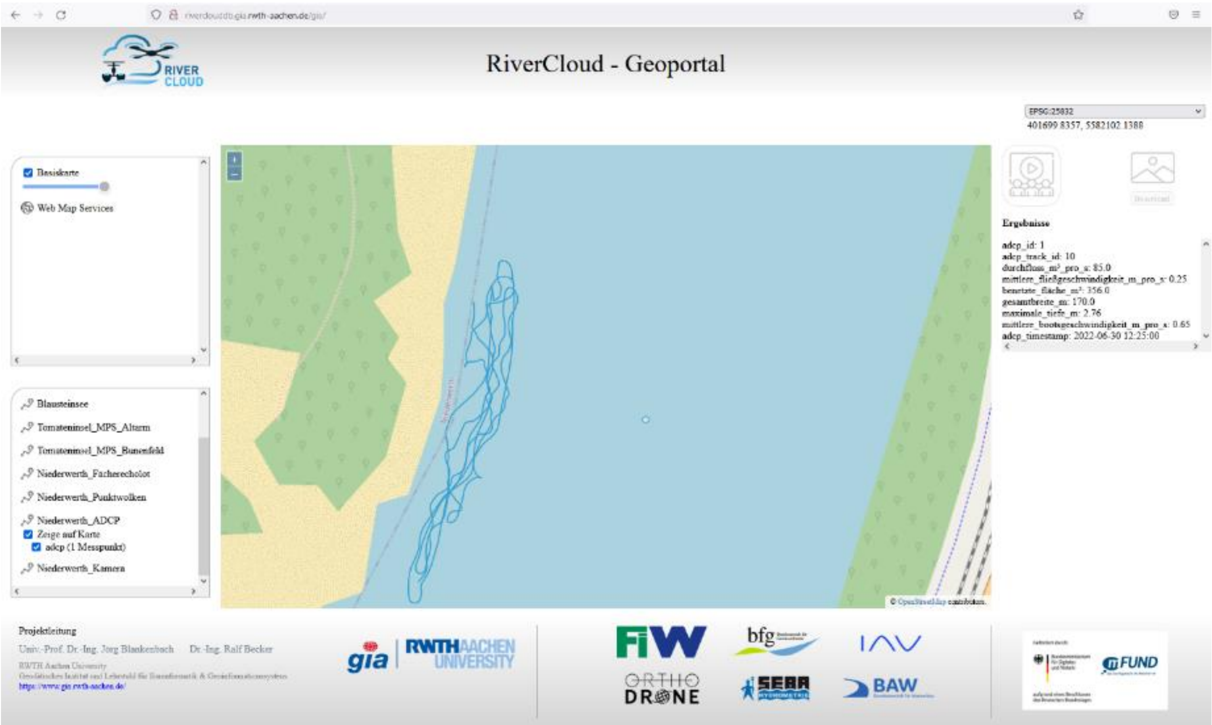

Fig. 9: RiverCloud web portal

7. SUMMARY/OUTLOOK

With the RiverCloud tandem of UAV and USV, a system is being developed that allows a highresolution acquisition of various, heterogeneous water data of waterways.
Essential for sufficiently high accuracy, completeness and homogeneity of the acquired data is the proper fusion of data. This requires a sufficiently good georeferencing of the data at any time, even if the commonly used GNSS is unavailable. In order to bridge or support the insufficient GNSS georeferencing, a novel pose estimation approach is being developed which combines several sensor data (GNSS, IMU, USV images and UAV tracking data) to improve the georeferencing of the USV and the collected water body data.
The basic functionality of the presented approach was already proved in the conducted surveys. The RiverCloud data provisioning strategy was delineated and the RiverCloud web portal was populated with data from the tests conducted.
The current work focuses on the one hand on the further development and refinement of the pose estimation approach and on the other hand on the improvement of the overall system including further survey drives on different water bodies. So far we have explored a stereo camera system for V-SLAM since it does not have the challenge of scale estimation due the fixed base line between the two cameras. However, we also plan to further explore a monocular

V-SLAM approach for a single-lens camera later. Additionally we will use the UAV camera to track the USV and thus improving the pose estimation of the USV. In this context, future captured data will follow within the still ongoing RiverCloud project.

8. ACKNOWLEDGEMENTS

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