Geodätisches Institut
und Lehrstuhl für
Bauinformatik &
Geoinformationssysteme

RWTH AACHEN UNIVERSITY

RiverCloud

Development of an autonomous and networked UAV/USV tandem system for the collection and provision of high-resolution data for water management and the expansion and maintenance of waterways

Technical Manual

SPONSORED BY THE

Federal Ministry
for Digital
and Transport

mFUND
Das Startkapital für die Mobilität 4.0

RIVER CLOUD

Imprint

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- SEBA Hydrometrie GmbH & Co. KG, Kaufbeuren
- Orthodrone GmbH, Kiel
- Bundesanstalt für Gewässerkunde, Koblenz
- Bundesanstalt für Wasserbau, Karlsruhe

This report is a product of the funding measure “RiverCloud – UAV/USV-Tandemsystem für Management und Unterhaltung von Wasserstraßen” funded by the German Ministry for Digital and Transport (BMDV) under funding code 19F2121A-G. The sole responsibility for the content of this report lies with the authors.

www.rivercloud.org

Content

Preface

Advances in digitalization is creating new opportunities for the collection and provision of geodata developments in the field of data acquisition sensor technology, including the use of uncrewed vehicles (e. g. drones), can lead to a continuous improvement in the quantity and quality of data. These technologies can be used for a wide variety of applications, including optimizing waterways as a mode of transport. An up-to-date and accurate database on the condition of the federal waterways and associated structures is necessary in order to plan and implement expansion and maintenance measures in line with requirements.

RiverCloud starts at this point as a novel and networked tandem system consisting of UAV (Uncrewed Aerial Vehicle) and USV (Uncrewed Surface Vehicle). It collects geospatial and geometric data of shallow water areas, groynes, hydraulic structures, vegetation at river margins, flow velocities and water quality parameters, presenting a holistic view of the federal waterway. The system could serve as a component for the consistent and effective monitoring and management of waterways and the aquatic environment (foreland, cut-off meander), including the consideration of economic and ecological aspects. The project objective was the development of modular sensor technology and procedures. The resulting protocols can be combined to fit the needs of a specific application, providing data for (traffic-) hydraulic engineering, water management and ecological questions.

Technical Aspects and data products will be presented in the following technical manual. Particular emphasis will be given to the the functionality of the measurement platforms, sensors used, and the concepts for effective data acquisition campaigns.

BfG
Bundesanstalt für
Gewässerkunde

BAW
Bundesanstalt für Wasserbau

1 RiverCloud: USV and UAV

1.1 Quick Facts

PROJECT

UNIQUE SELLING POINT

Coupled USV-UAV tandem system collecting consistent, spatially and temporally high-resolution data (e.g. water quality, vegetation structure, under- and overwater structure geometry, watercourse topography)

PROJECT PERIOD

06/2020 – 11/2023

1.2 Tracking for GPS accuracy

The term "tracking" gets a special meaning in the scenario of water edge surveys. In this instance, the UAV has the task of automatically following ("tracking") the USV and determining its position based on camera data. This position data is used in post-processing to improve the position calculation of the USV payload.

Functionality

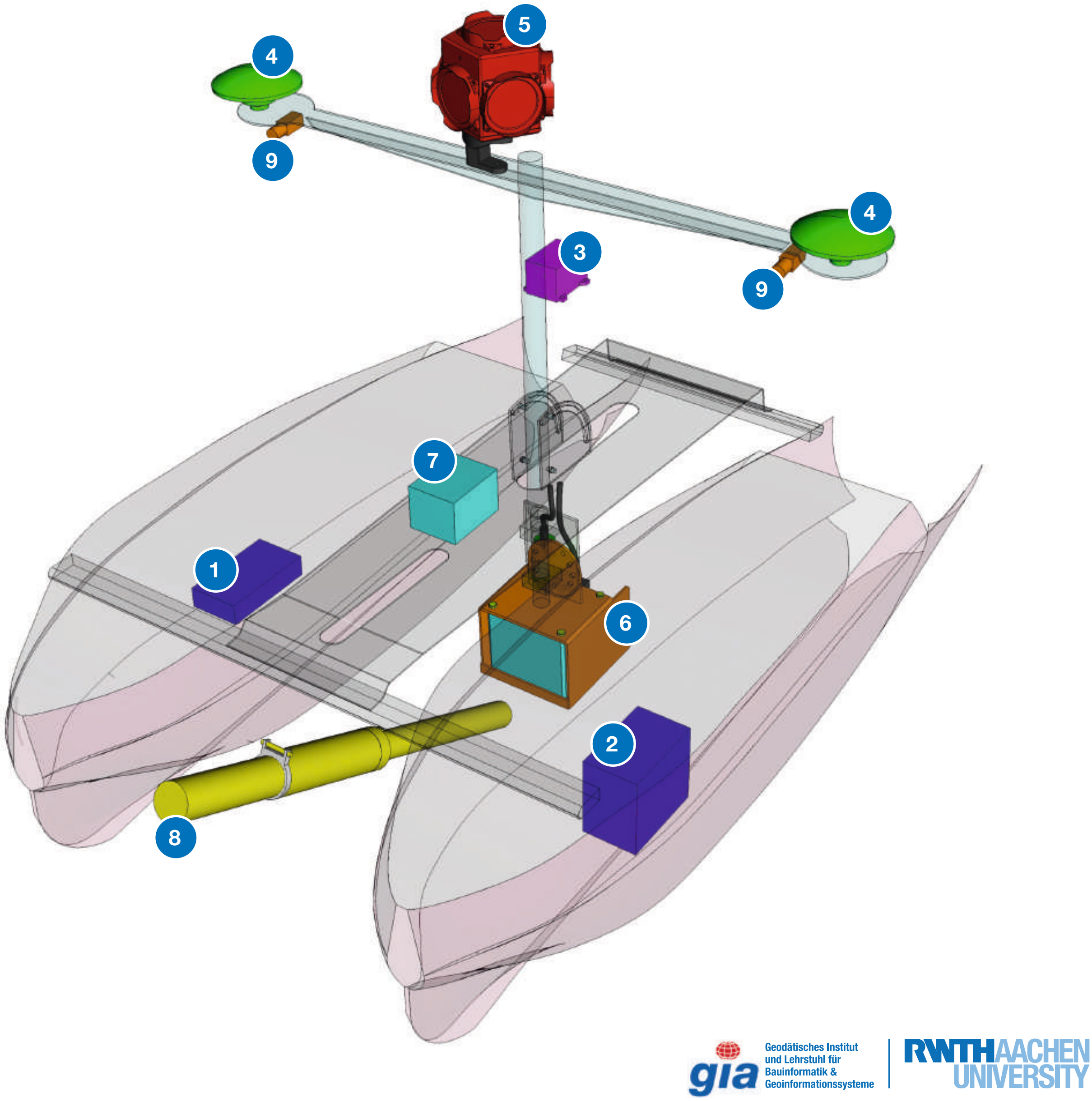
For tracking, the USV has to be equipped with special markers. These markers are and detected in the camera image collected by the UAV. The USV position is calculated by linking (right word choice?) the sensor data to the position and attitude of the UAV together with the position of the markers in the image.

This position data serves two purposes. It provides real-time feedback during the mission and is stored for post-mission use in improving position calculations for the USV. This is particularly advantageous if the USV GPS position is distorted, for example by structures such as sheet pile walls, lock chambers, or vegetation. The data are stored in NMEA format, include a time stamp, and contain the following information:

GGA – Position (longitude, latitude, altitude)
HDT – Orientation (= yaw angle)
VTG – Speed over ground (Ground Speed)
CSP – Time & Date
GST – Data quality (= standard deviations of the position data)

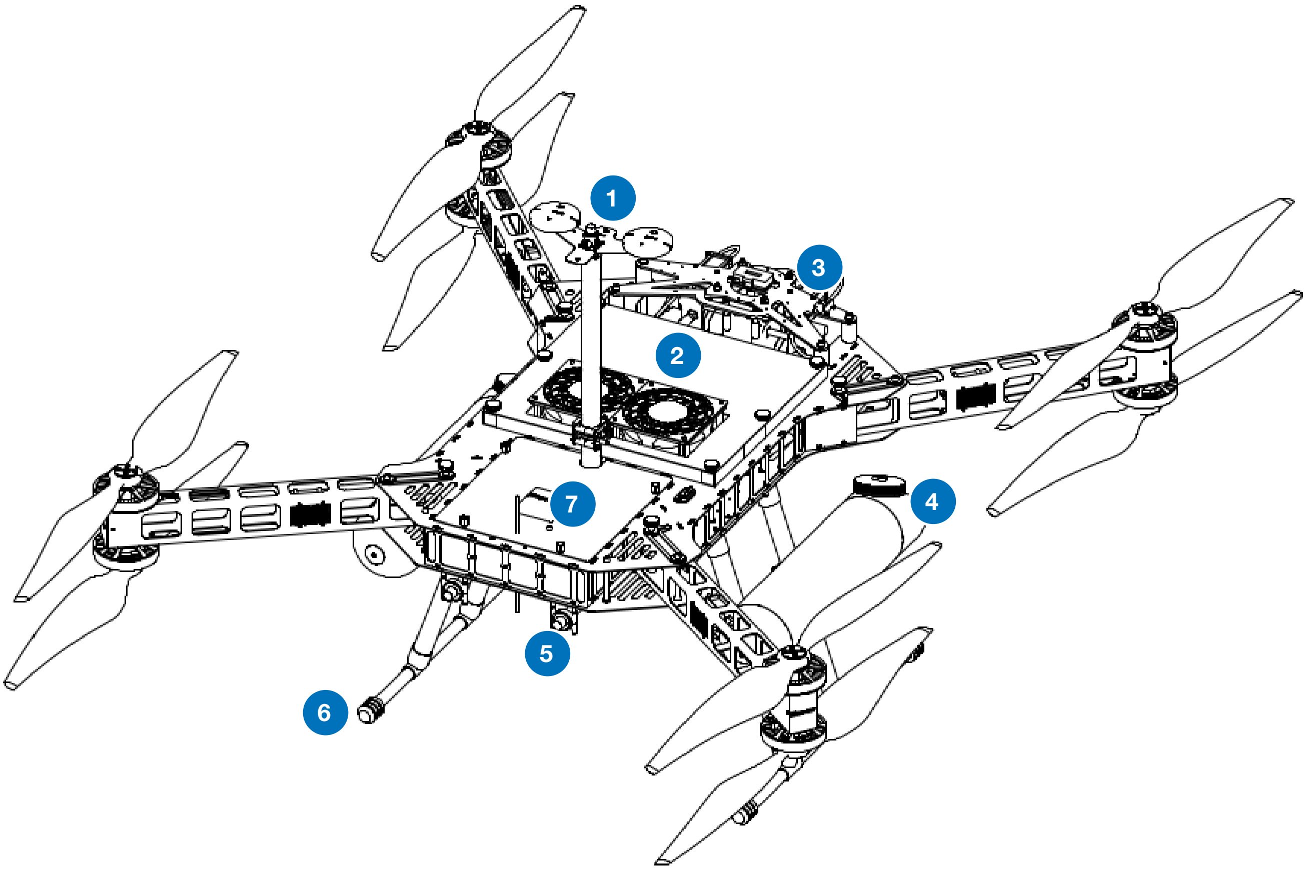
2 Components

USV



1	Onboard-Computer	4	GNSS-Antennas	7	Sonar Interface Module
2	Battery	5	Panoramic Camera	8	Multi Parameter Probe
3	Inertial Navigation System	6	Multibeam Echosounder	9	Stereo Cameras

UAV



1	Dual GPS Antenna	5	Payload Bay
2	Onboard Procesing Unit	6	Landing Gear
3	Power Generator	7	Autopilot
4	Tank System		

3 Mission Profiles

Building Survey

1. Mission	Surveying in the drone tandem	
Target	• Recording of the structure underwater (USV) • Tracking of the USV by the UAV for better position determination	
Sensors in use	USV	• Multibeam R2Sonic 2020 • Underwater camera • 360° camera FLIR Ladybug 5
	UAV	Tracking camera + 20 mm lens
Control	USV	USV is controlled according to the structure
	UAV	UAV keeps a constant eye on USV via tracking camera
Flight altitude	UAV	max. 47 m
Sensor setup	UAV	#2; tracking camera + lens 20mm, Phase One iXM 100 with 35 mm lens
Other		Deployment / calibration of control points necessary for intersection of point clouds

2. Mission	Measuring operation above water photogrammetry by UAV	
Target	Recording of the structure above water	
Sensors in use	USV	360° camera FLIR Ladybug 5
	UAV	PhaseOne iXM 100 with 35 mm lens in gimbal
Control	USV	Track mode autonomous or manual at close distances
	UAV	Flies a photogrammetric survey
Flight altitude	UAV	Individual according to structure for target GSD of 0.5 cm
Sensor setup	UAV	#2; tracking camera + lens 20mm, Phase One iXM 100 with 35 mm lens
Other		Deployment / calibration of control points necessary for intersection punk clouds

Accuracies:
- Ground resolution/resolution of orthophotos = 0.5 cm
- Recording channels RGB
- Resulting resolution
  - min. 10 cm underwater point accuracy
  - 1 cm above water point accuracy
- Local (existing) coordinate system – no transformation into superordinate coordinate system
- Specification of the accuracy of the individual recorded areas (e.g. above/below water)
- The 3D point clouds are to be delivered in *.laz format and *.csv format

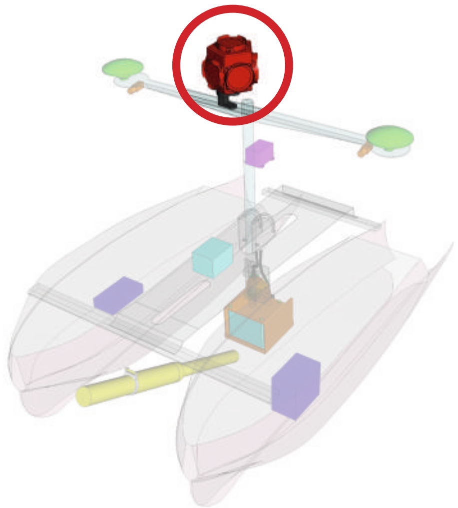
Watercourse survey

3. Mission	Recording of the DTM – over water	
Target	Photogrammetric survey mission for the acquisition of orthophotos and surface topography	
Sensors in use	USV	Not in use
	UAV	PhaseOne iXM 100 with 35mm lens gimbal
Control	USV	–
	UAV	UAV flying a photogrammetric mission – planning orthodrone
Flight altitude	UAV	~ 47 – 100 m (further tests necessary to determine)
Sensor setup	UAV	#3: PhaseOne iXM 100 with 35 mm lens Gimbal NIR camera (tbd) Gimbal
Other		Target GSD = max. 2 cm

4. Mission	Recording of the vegetation	
Target	Photogrammetric flight mission for three-dimensional recording of riparian vegetation	
Sensors in use	USV	360° camera FLIR Ladybug 5
	UAV	PhaseOne iXM 100 with 35 mm lens Gimbal NIR camera (tbd) Gimbal
Control	USV	Travels autonomously or manually parallel to the shoreline at the closest possible distance
	UAV	UAV flies a photogrammetric mission – planning orthodrone
Flight altitude	UAV	tbd (further tests necessary to determine)
Sensorsetup	UAV	#3: PhaseOne iXM 100 with 35mm lens Gimbal NIR camera (tbd) Gimbal
Other		If applicable, use of Ladybug camera footage from 1st measurement mission

Data delivery:
- Resulting resolution = 25 cm
- Geodata are to be transferred in the coordinate system ETRS89/DREF91 in the realisation 2016 – DHHN2016 + GCG2016
- 5 cm accuracy in position and height (SAPOS accuracy)
- Specification of the accuracy of the individual recorded areas (e.g. above/below water)
- The 3D point clouds are to be delivered in *.laz format and *.csv format
- Representation in the 3D – Datacube

4 Factsheets Components



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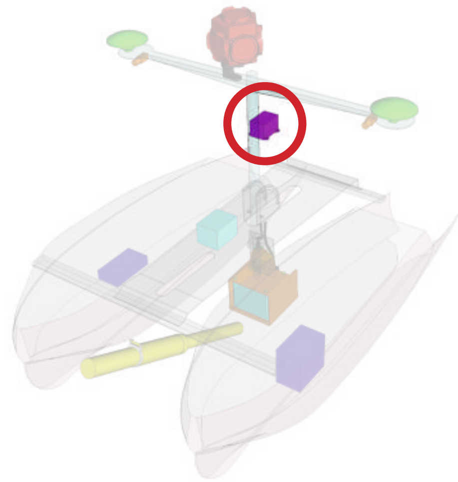
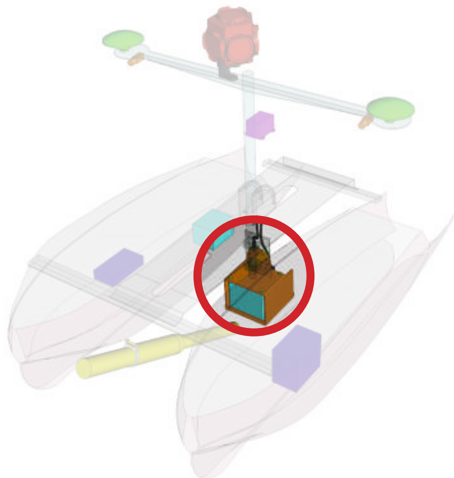
Panoramic camera FLIR Ladybug 5

Main Task	Acquisition of georeferenced panoramic images of the aquatic environment, especially vegetation and structures
Main Contact Person	GIA
Mounting Position	The camera is mounted on the swiveling mast, about 1 m above the water surface. The relative position to the INS is calibrated so that the absolute position can be registered for each image.
Specifications	• 6 Cameras with 5 Megapixel CCD-Sensor Sony ICX 655 • Global Shutter • A/D Converter 12 Bit • Resolution panoramic image: max. 8192 x 4096 Pixel (12 Bit) • Angular resolution: 0.044° (corresponds to 7.7 mm at 10 m distance) • Maximum frequency: 10 Hz • Transfer rate USB3 5 GBit/s
Software	• Recording of raw data with Ladybug Recorder (configuration of image format, exposure, frequency) • Image enhancement, exposure correction, stitching and conversion to spherical panoramas with Ladybug Capture Pro
Settings for data recording	• Image format JPEG 12 bit • Frame rate 1 – 2 Hz • Exposure metering only with the horizontally aligned cameras
Export of panoramic images	Spherical panoramas 8192 x 4096 pixels, image format JPEG



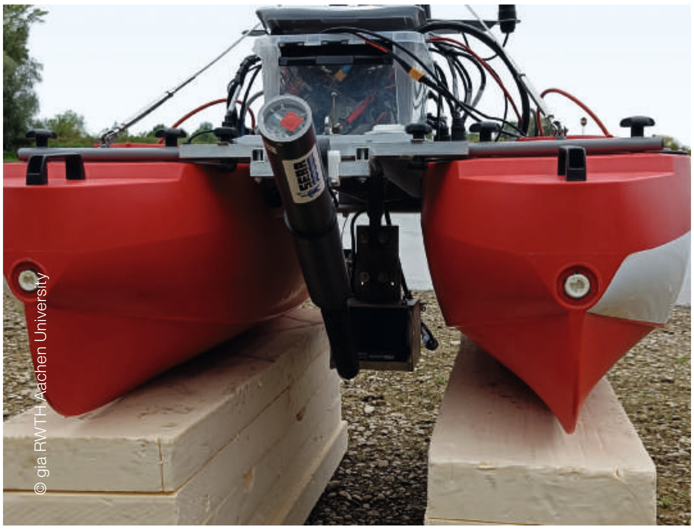
GNSS and Inertial Navigation System NovAtel SPAN CPT7

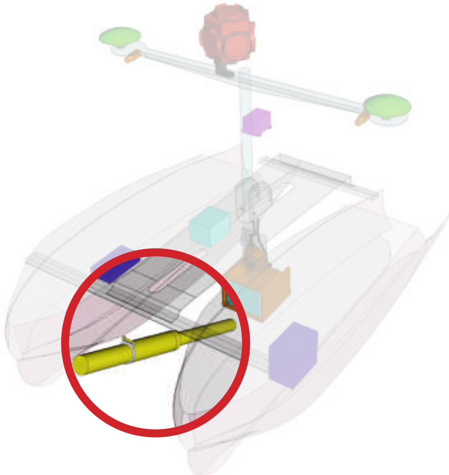
Main Task	Continuous determination of the position and orientation of the vehicle frame with all sensors
Main Contact Person	GIA
Mounting Position	The INS is mounted to the mast and the relative position to the two GNSS antennas and to the other sensors is precalibrated.
Specifications	• Compact GNSS and INS receiver, 555 Channel • MEMS IMU Honeywell HG4930 • Position Accuracy: 1 cm + 1 ppm RMS (RTK-Mode) • Time to first fix: < 39 s (cold start, no almanac or ephemeris and no approximate position or time) • Data rate - GNSS Position: 20 Hz - INS Position/Attitude: 200 Hz
Configuration	• Position data and time stamps are sent via Ethernet to the Sonar Interface Module and additionally to the onboard computer where the QINSY software records the data. • The correction data for measurements in RTK mode are received via NTRIP (AXIO-NET). The 4G modem must be equipped with an active SIM card for this purpose and there must be a stable internet connection. • For monitoring the current position, attitude, accuracy, satellite status, etc., the INS provides a web user interface (browser-based).
Data Recording	The QINSY software on the onboard computer is started remotely via the Remote Control Workstation. The recording of data from the INS and multibeam echo sounder is controlled with the Qinsy Controller.



Multibeam Echosounder R2Sonic Sonic2020

Main Task	Continuous recording of the underwater topography with ultrasound
Main Contact Person	GIA
Mounting Position	The multibeam echo sounder is attached to the bottom of the swiveling mast together with the sound velocity probe. The orientation of the sensor is normally vertically downwards, but can be rotated up to 30° to the left and right, in example for recording vertical structures. The transducer is located about 16 cm below the water surface. The minimum measurable water depth is approximately 0.7 m.
Components	• Multibeam Echosounder R2Sonic Sonic2020 • Sonar Interface Module (SIM) • Sound Velocity Probe Valeport miniSVS
Specifications	• Frequency range 200-450 kHz (UHR 700 kHz) • Beamwidth at 450 kHz 2° x 2°, at 700 kHz 1° x 1° • Up to 1024 soundings per ping • Swath sector 10° to 130°, UHR Swath sector 10° to 70° • Depth rating 100 m, max. range > 200 m • Pulse length 15 µs to 1 ms • Pingrate up to 60 Hz • Power consumption SIM and sonar head 34 W • Weight (Sonar Head) 4.4 kg
Software, Configuration, Control	The configuration is done via the Sonic Control 2000 software on the onboard computer. For optimum measurement results, the settings such as measurement mode, pulse width, power, gain, range, gate, sector angle and sector rotation angle must be constantly monitored and adjusted if necessary.
Data Recording	The QINSY software on the onboard computer is started remotely via the Remote Control Workstation. The recording of data from the INS and multibeam echo sounder is controlled with the Qinsy Controller. Due to QPS license restrictions, it is not possible to use Remote Desktop, instead Team Viewer must be used.





Multi-parameter probe (SEBA MPS-Qualilog-8)

Main Task	Recording water quality data
Main Contact Person	FiW
Mounting Position	The Multi Parameter Probe is mounted at an angle, centred on bow of the USV. The sensors underwater face the rear of the USV. To fix the probe to the USV, a custom mount was 3D-printed that connects the fastening of the probe to a removable rail system of the USV. The mount allows for light movement of the probe (e.g. from water movement).
Specifications	see table below

Specifications

Parameter	Measuring Range	Accuracy	Resolution
Temperature	-5...50 °C	+/-0,1 °C	0,01 °C
Conductivity	0...200 mS	+/-1µS/cm (0…200 µS/cm)	0,001 mS/cm
Salinity	0...70	+/-0,2 (0...16); +/-0,8 % (> 16)	0,01
TDS	0...200.000 mg/l	–	–
pH-Value	0...14 pH	+/-0,1 pH	0,01 pH
O_2-concentration	0...25 mg/l	+/-0,02 mg/l	0,001 mg/l
O_2-saturation	0...400 %	+/-0,5 %	
Ammonium	0,2...18000 mg/l	+/-2 mg/l (24 h), +/-5 %	0,01 mg/l
Turbidity	0...1000/5000 NTU	+/-1 %	+/
TSS	approx. 5 times the measuring range Turbidity mg/l		

Configuration	Configuration, as well as calibration, is carried out pre-survey with the software SEBAConfig.
Data Recording	The probe is switched on by the button on top of the probe. After switching on, the probe collects data using the configuration done pre-survey. Since the electricity consumption is quite low, resulting in a long runtime, we recommend turning on at an early stage of the USV setup to allow focus for more runtime limited sensors. Data is stored on an internal memory and can optionally be transmitted via Bluetooth and linked to onboard computer in real time.
Software	SEBAConfig is used for setup and calibration. If the probe was not linked to the onboard computer during the survey, no GPS-data is given. In this case postprocessing using GIS-software is required to match it with GPS-data via timestamps.

Acoustic Doppler current profiler (Teledyne StreamPro ADCP)

Main Task	Collect complete streamflow measurements
Main Contact Person	FiW
Mounting Position	The ADCP is mounted on a small floating device, which is connected to the USV with a cantilever attached to the same rail system as the multi parameter probe.
Specifications	• 2 MHz converter frequency • High precision profiling (broadband) • 20°beam angle • Measuring range: 10 cm - 6 m • Number of cells: 1-30 cells, cell size: 1 cm to 20 cm • Velocity range: ±5 m/s • Accuracy: ±1 % • Resolution: 1 mm/s (v), 1 mm (h) • Integrated temperature sensor: 4 °C to 45 °C • Integrated compass: 0-360°, ±1°accuracy • Tilt (pitch and roll): ±90°, accuracy ±0.3° • Total weight: 5.9 kg • Dimensions: Carrier boat: 42 x 70 x 10 cm • Communication: Bluetooth
Configuration	The trajectory has to be setup using the USV steering capabilities
Data Recording	Data is collected in real-time and transmitted via a wireless data link to a tablet or PC and displayed with Teledyne RDI (WinRiver) software.
Software	WinRiver

Bathymetric LiDAR Riegl BDF-1 (topo-bathymetric range finder with a green laser from RIEGL Laser Measurement Systems)

Main Task	Recording of terrain profiles and water depths in shallow water areas. Automatic internal data recording, georeferencing integrated. Due to the optical measurement method with a visible green laser, the penetration depth depends on the turbidity of the water body and can be a few dm to several m.
Main Contact Person	GIA
Mounting Position	The BDF-1 is firmly attached to a carrier plate, which is fastened under the UAV with four screws. The GNSS antenna must be mounted above the drone in order to get best satellite signal quality. Additionally, only one cable for the power supply (12-34 V, typically 50 W) has to be connected.
Specifications	• Laser Wavelength 532 nm (green) • Single laser beam measurement with active pitch compensation • Max. effective Measurement rate 4000 measurements/sec • Achievable Secchi depth 1.5 at 40 meas./sec (100 pulses averaged) • Laser beam footprint 20 mm at 20 m distance • Flight pattern: Cross sections from 20 – 50 m flying altitude
Configuration	The configuration is done via configuration files, which are processed when the BDF-1 is started. Via a computer with Ethernet connection to the device, the configuration files can be modified and transferred via Telnet and FTP.
Data Recording	The laser is automatically switched on as soon as the integrated Applanix IMU has found a good solution. Data recording then takes place automatically on the internal SD card.
Software	The evaluation of the data takes place exclusively in post-processing • Calculation of the trajectory with Applanix PosPac • Transformation and georeferencing of the raw data with RiWorld • Filtering and classification and export of the data with RiProcess

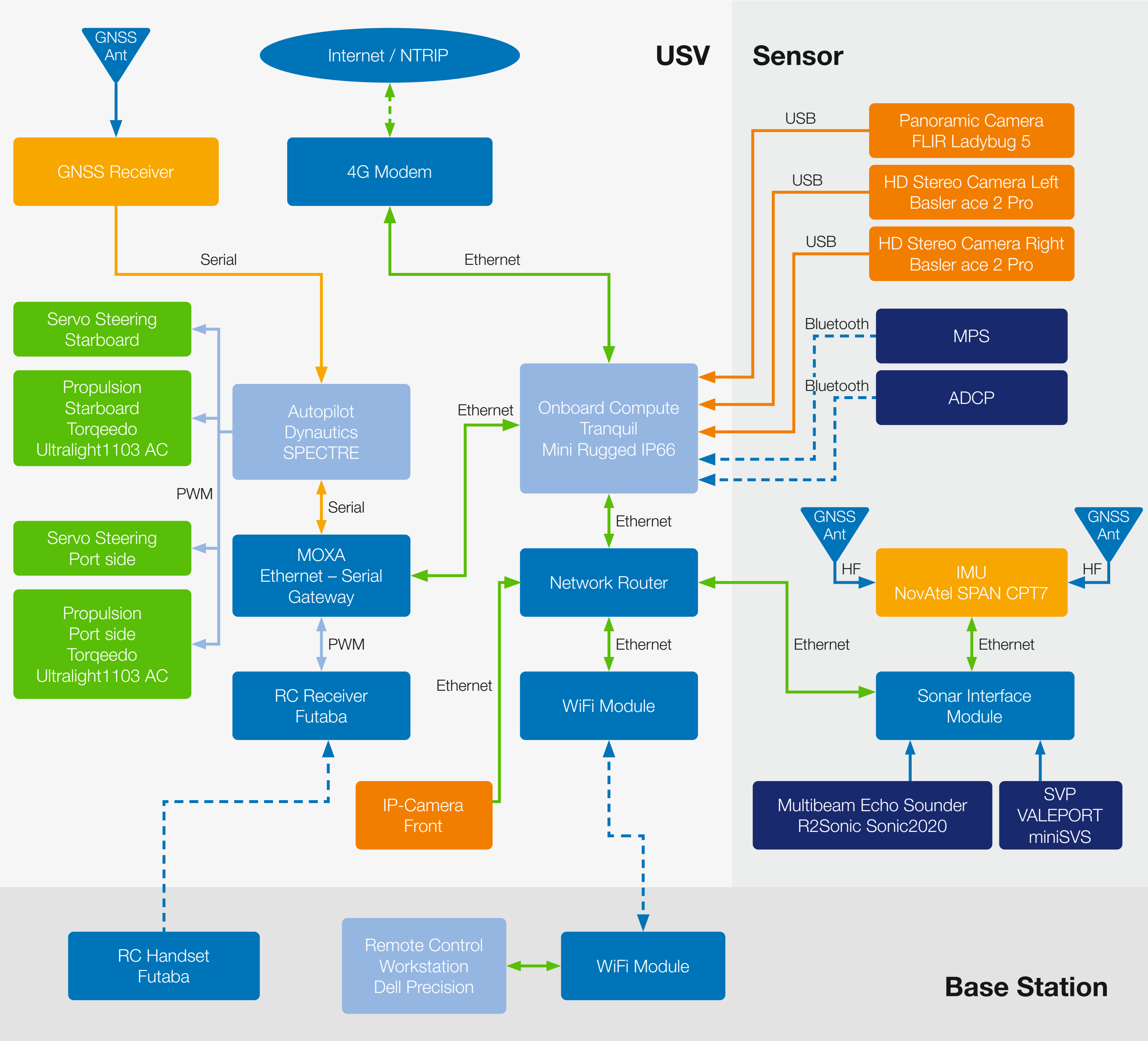
Metric medium-format camera (100 MP) with a 35 mm lens, by Danish Phase One

Main Task	Photogrammetry: This camera system has been effectively used for surveying and mapping water management facilities, vegetation, and shorelines.
Main Contact Person	Orthodrone
Mounting Position	In payload bay of UAV
Specifications	A live feed of the camera's view to the pilot's ground station is recommended for in flight data quality checks regarding light conditions and focus (when using a motorized lens).
Configuration	We recommend the use of a LiDAR range finder for consistent ground sampling distance (GSD) in NADIR and oblique imagery.
Data Recording	The point cloud data outputs were saved as *.laz format. Orthomosaics were also calculated and saved as georeferenced *.TIFF files.
Software	Agisoft Metashape was used for data processing, creating three-dimensional point clouds.

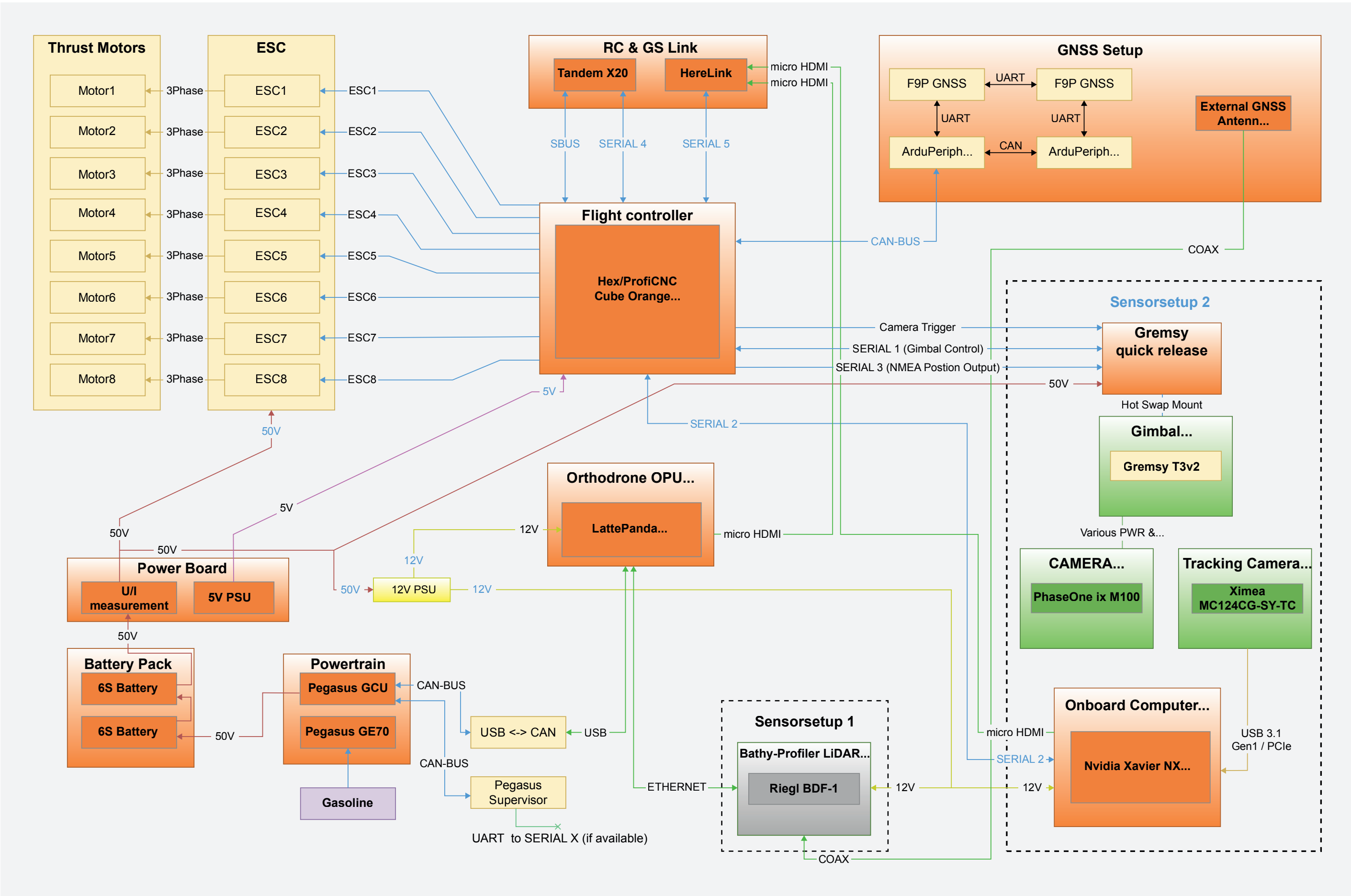
Sensor for Tracking and SSIV – a Ximea MC124CG-SY-TC camera with an 18 mm lens

Main Task	USV tracking and surface water flow velocity measurements [SSIV]
Main Contact Person	Orthodrone
Mounting Position	In payload bay of UAV
Specifications	An NVIDIA Jetson platform with software programmed by IAV provided onboard processing as well as control of the UAS through guide-mode during boat tracking. Other cameras or processing systems could be used for either of these purposes. However, the MC124CG-SY-TC fulfills image collection and onboard processing needs equally, making it a good choice for both USV tracking and surface water flow velocity survey applications. The Jetson proved light yet sufficiently powerful for the necessary calculations.
Configuration	The current setup relied on a remote connection to a second local PC for setup and triggering in-flight. While this was achieved through an on-site router, the the occasionally unreliable connection and short transmission distance of this setup would benefit from more sophisticated long-range downlink systems.
Data Recording	An HDMI live feed is advised to ensure data acquisition and image quality, as mentioned above.
Software	Onboard processing was done by in-house software from IAV.

5 System Architecture



System Architecture USV



System Architecture UAV

A highly modified version of the Avartek Boxer Hybrid, an Uncrewed Aerial Vehicle (UAV) manufactured by Finnish company Avartek, was selected as the UAV platform for these flight missions. The Boxer is a multirotor, octo-x-layout UAV with 25 kg maximum takeoff weight (MTOW). Its gasoline fueled two-stroke combustion engine and onboard power generator allow for sustained flight times of up to several hours. It features a Cube Orange autopilot system; dual GNSS; onboard-processing unit; and a modular, flexible payload bay for readily swapping between specialized sensors.

This platform was primarily selected for its long flight time and customizability. Given this research project's multi-mission scenario, it was important to have an onboard processing unit for both enabling and simplifying the integration of different sensors.

Deployments featured bathymetric lidar as well as photogrammetry missions, uncrewed surface vehicle (USV) tracking, and measurement of surface water flow velocity (SSIV). We implemented a custom gimballed, multi-camera payload to allow for the latter three mission profiles without necessitating the removal or mounting of payloads between missions. This including an additional, second (ARM-based) onboard computer running custom software for SSIV measurement as well as boat tracking and UAS navigation. Off-the-shelf products cannot be recommended as their closed systems lack the necessary adaptability and interface accessibility.

6 Data Products

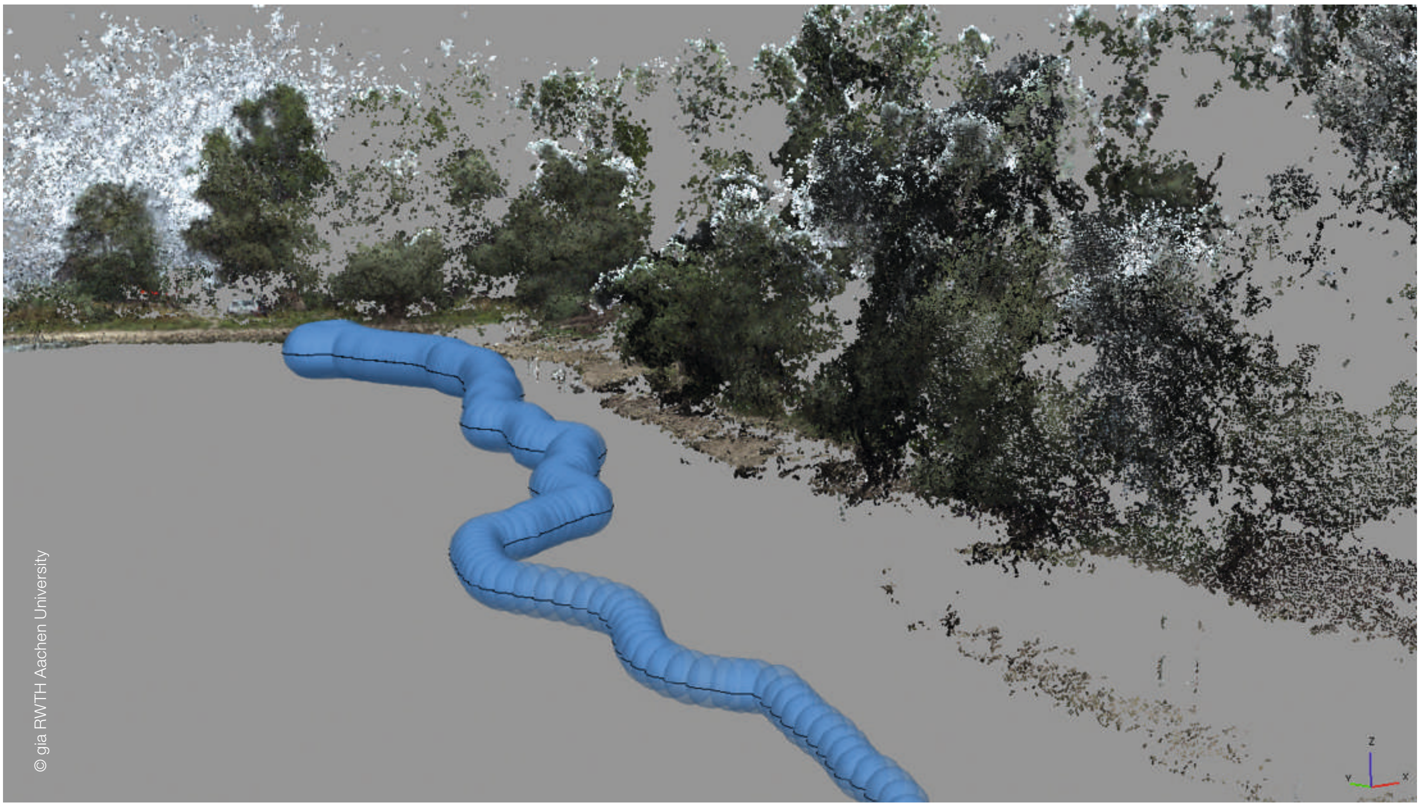
Panoramic Images

Content	Stitched and corrected color images from panoramic camera with georeferenced information
Projection	360° x 180° spherical or cylindrical projection
Size	8192 x 4096 Pixel
Resolution	0.044° per pixel, 15.3 mm at 20 m distance
Format	RGB 24 Bit Color, JPEG
Georeference	• Horizontal Position: East, North in ETRS89 • Height: DHHN2016 • Attitude: Heading, Pitch, Roll

Sample spherical panoramic image

3D-Pointcloud from panoramic camera

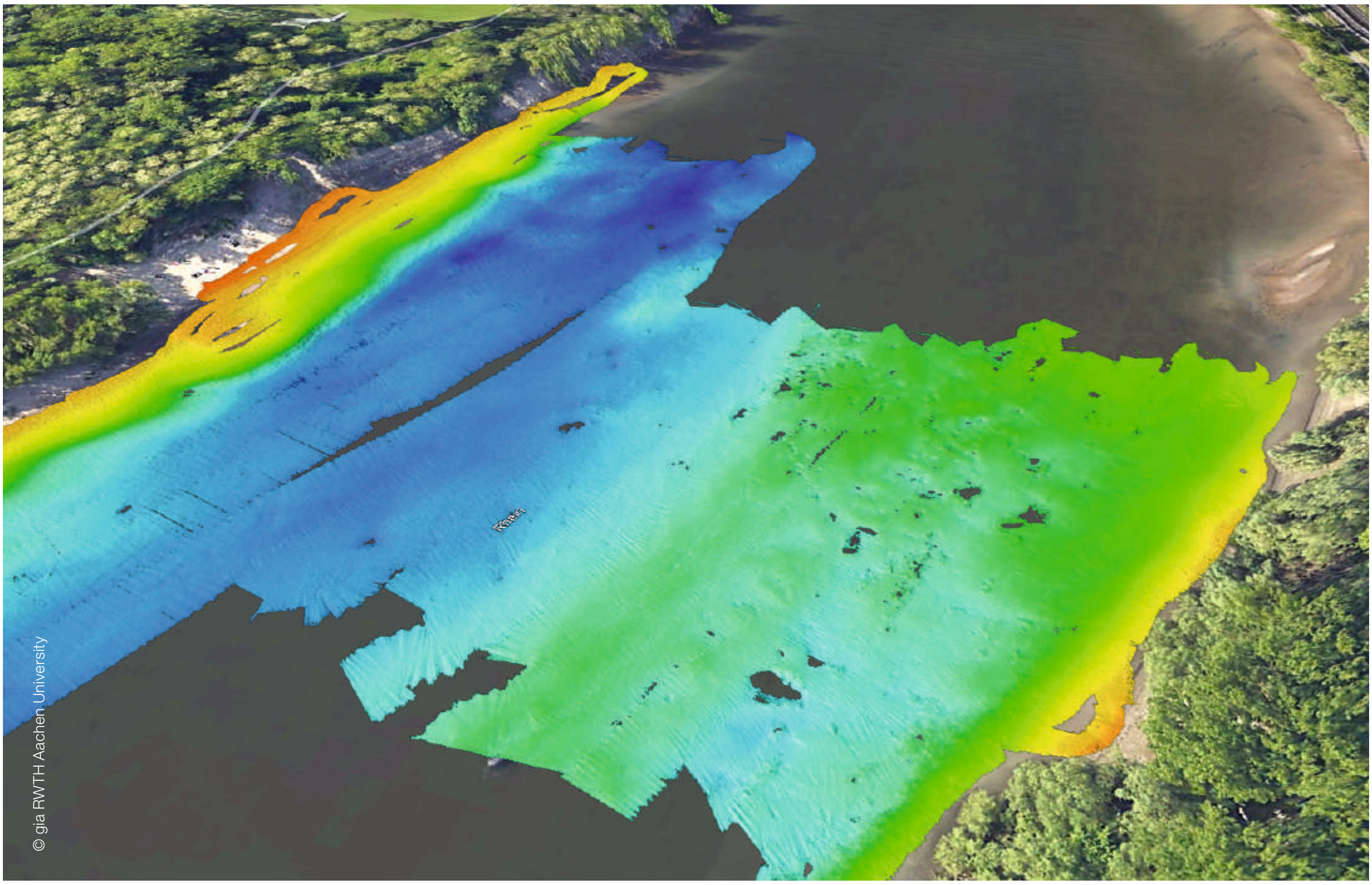
Content	3D colored pointclouds of bank area above water, calculated from panoramic images
Resolution	Irregular full resolution (approx. 2 to 10 cm distance) or resampled lower resolution with fixed minimum distance between points
Format	Binary Format LAS version 1.2 https://www.asprs.org/divisions-committees/lidar-division/laser-las-file-format-exchange-activities or ASCII text file (X, Y, Z, R, G, B) Position coordinates in unit meter with 3 decimal places, RGB Color values integer 0..255 Small areas with low resolution fit into a single file, large areas with more than 10 Mio. Points can be splitted into rectangular tiles.
Georeference	• Horizontal Position: East, North in ETRS89 • Height: DHHN2016



Perspective view of camera positions and 3D colored pointcloud from panoramic images

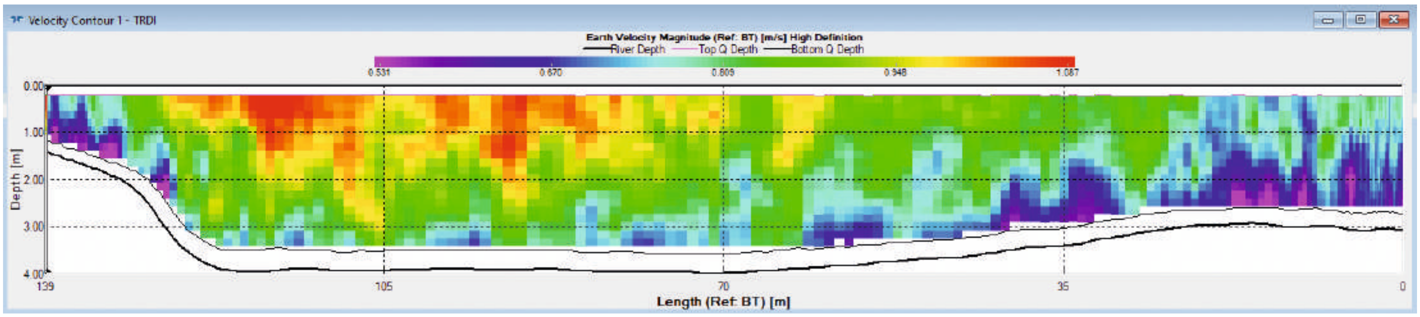
Digital terrain models of the watercourse (DGM-W)

Content	Surface model of underwater topography as a regular grid of height values or irregular triangulated network with 3D points.
Resolution	Irregular full resolution (approx. 2 to 20 cm distance, depending on the depth) or resampled lower resolution with fixed distance between grid points (i.e. 0.1 or 0.5 m).
Accuracy	Standard deviation of absolute height values approximately 2 to 5 cm
Format	• ASCII text file with list of 3D points in regular distance (*.xyz) • Only Height values of grid points in a rectangular area (i.e. ArcView Grid *.asc) • GeoTIFF with floating point values • GeoTIFF image with depth color values Small areas with low resolution fit into a single file, large areas can be split into rectangular tiles.
Georeference	• Horizontal Position: East, North in ETRS89 • Height: DHHN2016



Complete streamflow measurements

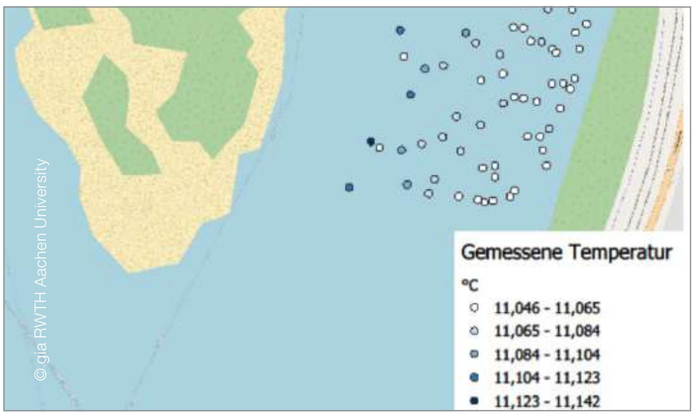
Content	Flow cross-section, flow velocity distribution, mean flow velocity, flow rate
Resolution	Minimum cell size 2 cm with up to 30 cells. Standard profiling range of up to 2 m (6 m with upgrade)
Accuracy	Velocity Accuracy (typical): ±1.0% of measured velocity or ± 0.2 cm/s
Format	• .PD0 • .mmt Both can be converted using software like WinRiver II
Georeference	- ? Depends on the Coordinate Reference System of the onboard computer.



Sample

Water Quality Data

Content	Equipped with up to 12 different sensors capable of measuring up to 16 different water quality parameters (depending on the setup).
Resolution	The spatial resolution depends on the measuring interval of the probe and the velocity of the USV.
Accuracy	The accuracy depends on the sensor under consideration (see component Multi Parameter Probe).
Format	.csv
Georeference	Depends on the Coordinate Reference System of the onboard computer.



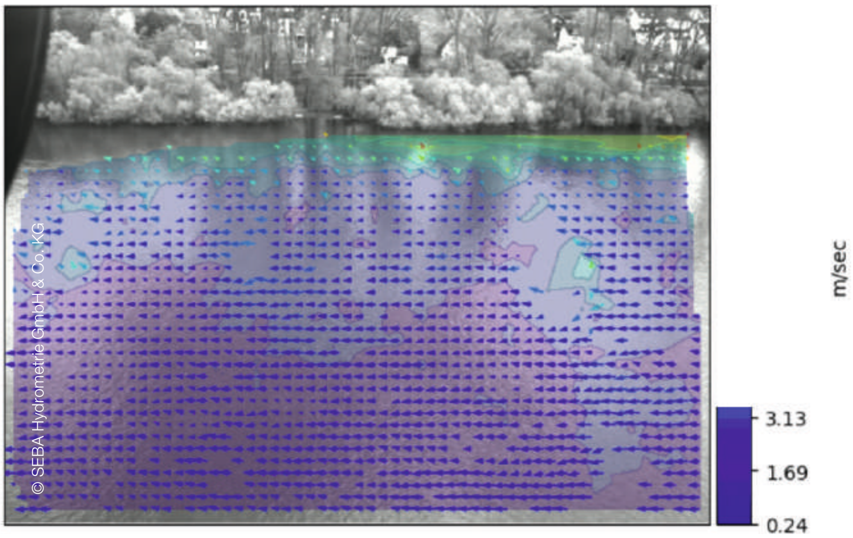
Sample

Point Clouds and Digital Surface Models (DSM)

Content	Digital surface models (DSMs) were generated from the point clouds, which in turn were used to calculate and export orthomosaics with a 20 mm/px resolution. We used Agisoft Metashape for photogrammetric processing of the georeferenced images and ground control points, manually and semi-automatically cleaning noise on the water's surface and around vegetation in the generated point clouds. For privacy reasons, content such as uninvolved people, car license plates, or other potential sources of personal data were removed from the data sets.
Resolution	The average GSD for photogrammetry above-water facilities is 5 mm/px. This value may vary slightly between use case scenarios. Due to the experimental nature of this survey, no pre-determined resolution parameters were set for the bathymetric LiDAR data. Based on manufacturer recommendations, profile scans should be flown in a meandric pattern and at an altitude of approximately 20 m above the ground or surface of the water. The point resolution and accuracy depend among others on flight speed and water turbidity.
Accuracy	The accuracy of georeferencing was between 2 and 5 cm for both position and altitude.
Format	To allow data access for slower municipal systems the data were sub-sampled and tiled and shared as *.laz and *.GeoTIFF formats, respectively.
Georeference	All data was referenced as UTM Zone 32N (EPSG:25832, DHHN2016).

Camera-based flow measurement

Content	Surface Structure Image Velocimetry (SSIV) was applied to calculate mean flow velocity and flow rate at selected cross-sections in the study areas.
Requirements Camera	(1) As small and lightweight as possible, (2) Fast image transmission to computer unit for saving the images, (3) High resolution (1.2 cm/pixel at more than 15 m altitude), (4) Configurable via programming interface. Therefore, the Ximea-Kamera MC124CG-SY-TC mounted to the UAV was used.
Workflow	After the Video is recorded and the Data transmission is completed, the water level position along with the natural features and the cross-sections are defined in a graphical user interface. Stabilization of the recorded video is applied if necessary. After these steps the flow velocities and flow rates are calculated.
Format	?
Georeference	UTM Zone 32N (EPSG:25832, DHHN2016).



Surface Structure Image Velocimetry at Niederwerth, Rhine River.

7 Transfer Options

The normal use case is data acquisition with the uncrewed carrier platform. This requires the USV pilot to have a visual of the full measurement area and the boat to remain within range of the radio remote control during remote operation. On flowing waters, a backup boat is required to intervene in the event of a technical failure.

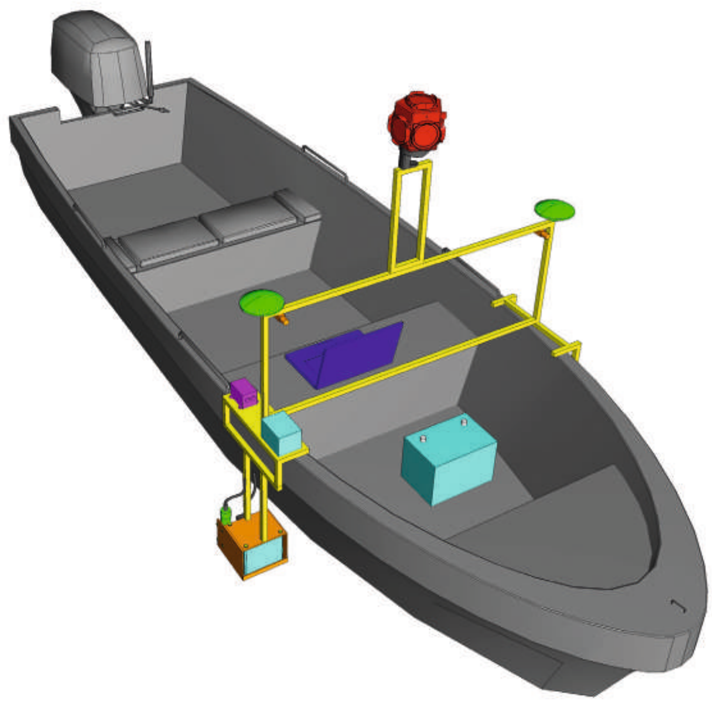
If the conditions for remote operation are not met, the sensors can also be used on another carrier platform such as a small motorboat with shallow draft. The sensors (INS, multibeam echo sounder, GNSS antennas and cameras) should either be mounted on a stable frame or mountable in such a way that the calibrated relative positions to each other are reproducible.

Though the specific application scenario will determine which UAV needs to be selected for a project, it is strongly advised that the chosen UAV include real-time kinematic (RTK) function for higher positioning accuracy and and support minimum flight times of approximately 40 minutes.

Photogrammetric surveys with high-end camera systems like the system deployed require a payload capacity at least 2 kg. This increases to roughly 6 kg for bathymetric surveys, which require the use of LiDAR sensors. A single-beam sensor only allows for profile scans of underwater topography while retaining a relatively low overall weight. Rotating-mirror systems are preferable for bathymetric surveys as they can cover more than a single profile but come with a significant weight penalty and require a payload capacity of 11 kg or more. If surveys call for vegetation mapping, the addition of a (red) LiDAR sensor may be required. Ideally, some of the different sensor packages for photogrammetry and LiDAR surveys could be integrated and used simultaneously.

The USV tracking and SSIV have lower requirements for payload capacity. The critical point lies in the interface between the autopilot system and the companion computer for flight control during .measurements, relying on the customized inputs and technical modifications of the uncrewed aerial platform. Not all autopilot systems are suitable for this purpose. Extra caution and attention are needed from the UAS operator and remote pilot when planning and selecting equipment for automated missions due to stronger flight regulations and safety reasons.

UAS with multi-sensor stabilization and long flight times give distinct advantages for the scenarios described. Tracking a full boat survey may require a flight time of several hours. To make these complex surveys feasible in the future, hybrid multirotor systems with high payload capacity and long flight times are needed to carry the combined multipurpose payloads for several hours beyond visual line of sight (BVLOS).

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