AUTOASSESS
AI & robotics for safe vessel inspection

D6.1 DATA STORAGE AND INTERFACE DEFINITIONS

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D6.1 DATA STORAGE AND INTERFACE DEFINITIONS

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Authors	Jaehyung Jung, Jiaxin Wei, Stefan Leutenegger (TUM)
Reviewers	Luca Zanatta (NTNU), Harmish Khambhaita (UZH), Rasmus Eckholdt Andersen, Melanie Brunhofer (DTU), Niek Beckers (CGN)
Abstract	The map server is a core element in autonomous vessel inspection with the main objectives as 1) Visualization of a 3D map and inspection results to human supervisors and 2) Supporting robot inspection missions by providing highly precise maps and navigation goals. Towards this goal, the map server maintains all the relevant sensor measurements and refines an offline map using available sensor observations from one or more UAS. This deliverable describes the overall data flow, data interfaces between the map server and UAS or UI-DSS, and a data structure for storage.
Keywords	Digital twin, Offline mapping

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EXECUTIVE SUMMARY

The map server is a core element in autonomous vessel inspection with the following two main objectives:

- visualization of a 3D map and inspection results to human supervisors,
- supporting robot inspection missions by providing highly precise maps and navigation goals.

To achieve this, the map server maintains all sensor measurements, defect annotations, as well as a post-processed 3D map and outputs queried data in a specified data format.

More specifically, the unmanned aerial system (UAS) collects sensor measurements such as lidar point clouds and visual images plus inertial measurement in a rosbag file and uploads them to the map server via the ground station (GS). Then, a highly precise offline map is estimated using all available sensor measurements. Saved images can be accessed anytime to annotate defects and structural semantic information for machine learning algorithms. 3D geometry maps as well as defect annotations and thickness measurements are visualized through a dedicated user interface & decision support system (UI-DSS) to end users where high-level mission planning can be made. On the other hand, for the inspection mission, volumetric maps and navigation goal positions are retrieved by the inspection UAS (IUAS) prior to its mission.

This deliverable describes the overall data flow from UAS to UI-DSS and data interfaces between the map server and GS or UI-DSS. Also, a data structure is presented with specified data formats.

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Abbreviations

UAS	Unmanned Aerial Systems
EUAS	Exploration UAS
IUAS	Inspection UAS
TIUAS	Tethered IUAS
GS	Ground Station
NDT	Non-Destructive Testing
BWT	Ballast Water Tanks
CH	Cargo Hold
NDT	Non-Destructive Testing
UI-DSS	User Interface & Decision Support System
DOF	Degrees Of Freedom
SLAM	Simultaneous Localization And Mapping
ROS	Robot Operating System
RGB	Red Green Blue
IMU	Inertial Measurement Unit
PCD	Point Cloud Data
CSV	Comma-Separated Values
JSON	JavaScript Object Notation

1 Overview of Data Flow

The objective of the map server is to visualize the vessel inspection data to human supervisors where the offline map serves as a core element for a decision support system. Raw sensor measurements and processed onboard data, collected by the UAS through their exploration and inspection missions, are transmitted to the GS and then uploaded to the map server. Depending on the UAS mission type, the map server data can later be retrieved by the UAS to support their navigation by providing prior 3D maps and interesting inspection spots. Fig. 1 summarizes the overall data flow of the map server, and the sections below describe the roles of each block.

- Map server

The map server extracts rosbag files recorded by UAS into a specified data format to streamline downstream tasks. A highly precise map ("offline map") is estimated using all available sensor measurements collected by UAS. The map server maintains raw sensor measurements as well as processed data and updates them when new data is available from future missions.

- UAS and GS

EUAS and (T)IUAS record raw sensor measurements (lidar point clouds, RGB images, inertial measurements) into a rosbag file and upload the rosbag to the map server via the GS. Also, the UAS provides processed data (state estimates and map) that may be refined in the map server. To support inspection missions, the map server provides the offline map and target positions for navigation.

- Visualization UI-DSS

The map server outputs visualization data of specified formats to the CGN's UI-DSS for high-level mission planning from end users. Structural defects, thickness measurements, and 3D geometry maps as point clouds are sent to the UI-DSS.

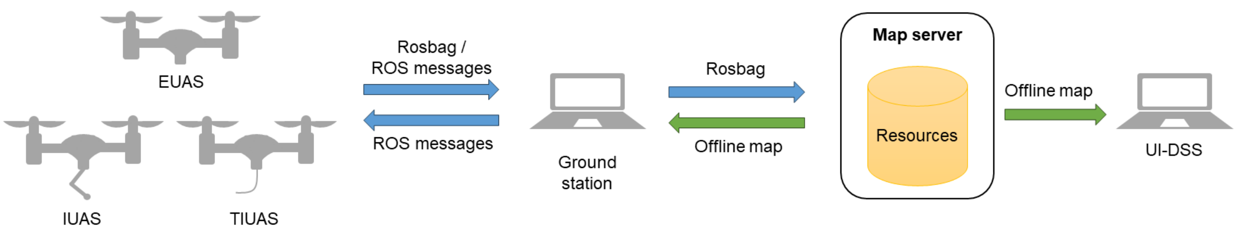

Figure 1: Data pipeline block diagram

2 Data storage formats for map server

The map server has inputs from the GS and converts rosbag files into a specified data format for further usage. The map server maintains 3D maps, visual images, and inspection results. A highly precise offline map is built based on raw sensor measurements and pose/map from onboard data. Visual images and other relevant data can be accessed by other partners to process data, for instance, machine learning algorithms to annotate structural defects. Thickness and defect annotations help high-level mission planning for end users. 3D map as volumetric representation is maintained for UAS navigation, while 3D map as point clouds is for visualization in the UI-DSS.

2.1 Data types

Table 1 summarizes all the required data in the map server. The 3D map maintains different types of map representation depending on its purpose. Attributes of 3D maps are easily extendable to include semantic information. Point clouds and semantic maps with proper visualization are informative for human supervisors for high-level mission planning. A volumetric map is a proper representation to check collisions during navigation.

On top of the 3D map, thickness measurements and RGB images with their 3D locations help to assess the vessel's health. RGB images can be accessed at a later stage for defect annotations.

Data	Type	Format
3D map	point cloud, volumetric map, semantic map, mesh	PCD, LAS, PLY, custom
Appearance	grayscale/RGB images	JPEG, PNG, CSV, TXT
Thickness	NDT measurements	CSV
Defects	segmentation mask image, 3D bounding volume	PNG, TXT, JSON

Table 1: Required data with their types and formats of the map server

2.2 Data structure of the map server

Stored data is organized as shown in Fig. 2. Data under this structure is updated if necessary when new data arrives after a UAS mission. The state estimate file includes the corresponding timestamp, camera pose, velocity, and sensor biases. Calibration files include focal length, principal point, resolution, and additional relevant information. Thickness measurements include 3D (x, y, z) locations in meter and probe information. Label files describe the mapping between defect types and corresponding masks.

This data structure is easily extensible by augmenting additional directories or attributes that can be identified at a later stage. In this regard, by maintaining camera poses and calibration parameters with a precise 3D map, forward and reverse indices can be established where end users can emphasize interest regions from 2D image to 3D map or vice versa.

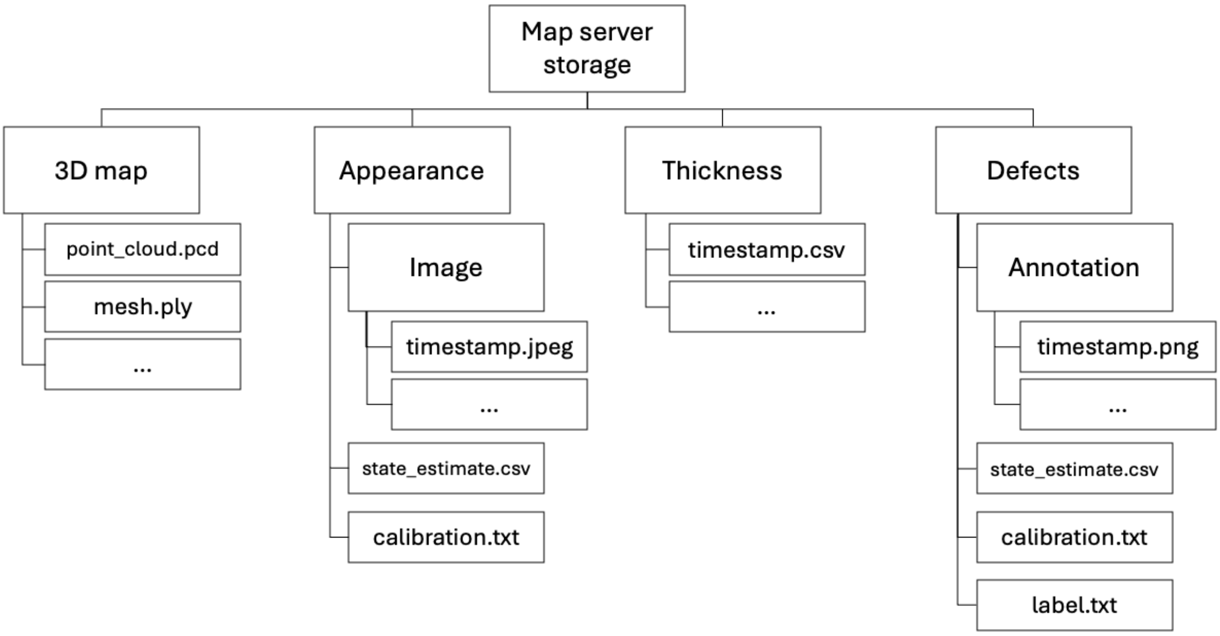

FIGURE 2: DATA STRUCTURE IN THE MAP SERVER

3 DATA INTERFACE BETWEEN MAP SERVER AND GS

Depending on the mission type, the EUAS or (T)IUAS transmits sensor measurements and their estimated states to the GS. Then, the rosbag file is uploaded to the map server after the mission. The GS serves as the communication bridge between the UAS and the map server. EUAS explores BWT and constructs 3D geometry based on its estimated poses, while (T)IUAS measures the thickness of BWT and CH structures through their NDT probes. After building the offline map from measurements of EUAS, relevant data can be pulled from the map server to support future exploration or inspection missions by providing a prior 3D map and semantic information.

In this section, input and output data between the GS and UAS are specified. This is closely related to Deliverable 4.1 and the data interface between UAS and GS can be found on Deliverable 4.1.

3.1 INPUT DATA FROM GS

UAS records raw sensor measurements for its exploration and inspection missions. Recorded rosbag file is uploaded or streamed (if connection is available) from GS to the map server. While the current development is based on ROS1, the middleware will be changed to ROS2 at the end of the project. Types of raw sensor measurements and their ROS1 (also compatible with ROS2) message types are summarized in Table 2.

Sensor	Data	Message type
LiDAR	point cloud	sensor_msgs/PointCloud2
IMU	angular rate, acceleration	sensor_msgs/Imu
Camera	grayscale/RGB image, events	sensor_msgs/Image dvs_msgs/Event dvs_msgs/EventArray
NDT probe	thickness with location, raw measurements	custom message

TABLE 2 : INPUT DATA (RAW SENSOR MEASUREMENTS) FROM GS TO MAP SERVER

Also, UAS estimates the robot pose and surrounding map during navigation. Onboard estimates are pushed to the offline map to serve as initial guesses of the refinement process. The processed data and their message types are summarized in Table 3.

Processor	Data	Message type
odometry/SLAM	6DOF pose	geometry_msgs/ PoseStamped
Mapping	point cloud, volumetric map	sensor_msgs/PointCloud, custom message

TABLE 3 : INPUT DATA (PROCESSED DATA) FROM GS TO MAP SERVER

3.2 OUTPUT DATA TO GS

The (T)IUAS retrieves inspection points and 3D map data from the map server in their inspection missions in BWT and CH. Table 4 summarizes the required data from the map server to the GS. A set of coordinates for the mission will be served as goal positions. The volumetric map supports UAS navigation in the environment previously explored by EUAS.

Data	Type	Format
Maps	semantic map, volumetric map, point cloud, mesh	PCD, PLY ,LAS, custom
Inspection mission	set of coordinates, approximated mission time	CSV, JSON

TABLE 4 : OUTPUT DATA FROM MAP SERVER TO GS

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4 DATA INTERFACE BETWEEN MAP SERVER AND UI-DSS

A 3D viewer provided by CGN will be augmented to include both semantic information and 2D imagery outputs from the map server to facilitate a comprehensive analysis of inspection results conducted by human supervisors. The goal is to allow end users to seamlessly navigate between detailed 2D close-up images and 3D overall views of the inspected areas. Semantic information will be utilized to emphasize regions of particular interest. Therefore, it is essential to define suitable data interfaces for effective visualization. It is worth noting that recent advancements in the Gaussian Splatting technique provide a new opportunity for creating a photo-realistic 3D map for real-time visualization.

4.1 OUTPUT DATA TO UI-DSS

We outline the data interface specifications between the map server and the UI-DSS in Table 5.

For map visualization, the interface will handle point cloud data (including 3D positions and colors) in the LAS or E57 format to provide a comprehensive 3D visualization of the inspected area. Another option is to visualize Gaussian splats defined in a customized PLY file (including 3D positions, scales, rotations, opacities, and color information) for photo-realistic rendering of 3D environments. RGB images accompanied by metadata (including state estimates and intrinsics) will be incorporated for 2D close-up appearance visualization in the 3D viewer. For the detailed data formats for the appearance interface, please refer to Section 2. NDT measurements in CSV format will be used to assess the thickness of various structures within the inspected area. Defect annotations will be managed as segmentation mask images, together with camera poses and intrinsics, to highlight and identify defects within the inspected structures, aiding in detailed analysis and inspection. The data formats for the defects interface will follow the same specifications defined in Section 2.

Data	Type	Format
Map for visualization	Point cloud	LAS, E57, PTX, PTS
Map for photo-realistic visualization (optional)	Gaussian splats	customized PLY
Appearance	RGB images with metadata	see Table 1
Thickness	NDT measurements	CSV
Defects	Segmentation mask image	see Table 1

TABLE 5 : OUTPUT DATA FROM MAP SERVER TO UI-DSS

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