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Dataset of the Intermediate Competition in Challenge MALIN: Indoor-outdoor Inertial Navigation System Data for Pedestrian and Vehicle with High Accuracy References in a Context of Firefighter Scenario

Authors

Ni Zhu[1], Miguel Ortiz [1], Valérie Renaudin [1], Cécile Ichard [2], Sander Ricou [2],

Affiliations

1. AME-GEOLOC, Univ Gustave Eiffel, IFSTTAR-44344 Bouguenais, France
2. SGME, France

Corresponding author(s)

Ni Zhu (ni.zhu@univ-eiffel.fr)
Sander Ricou (sander.ricou@sgme.com)

Abstract

This paper provides a multiple sensor dataset collected by the CyborgLOC team during the intermediate competition of the Challenge MALIN (MAîtrise de la Localisation INdoor), which is a competition for indoor/outdoor real-time positioning. The sensors, including a GNSS receiver Ublox NEO-M8N, a Realsense D435i stereo camera, three Xsens MTi-300 and one PERSY (PEdestrian Reference SYstem), are mounted on different parts of the subject's body. The PERSY is a foot-mounted positioning device with a tri-axial accelerometer, a tri-axial gyroscope, a tri-axial magnetometer as well as a GNSS receiver Ublox M8T. The two scenarios are designed in a training center of firefighters CFIS (Fire and Rescue Training Center) in Blois, France to simulate the situation of firefighters during interventions. With total distances around 2 km for each scenario, the travelled trajectories passed through challenging environments including indoor, outdoor, urban canyon. The indoor part contains different stair levels, from the underground up to the 6th floor. The travel modes are vehicles and pedestrians. Several classical activities of firefighters are realized such as walking, running, stair-climbing, side-walking, crawling, passing above/below obstacles, carrying a stretcher, ladder climbing, etc. High accurate ground truth of stationary points and enclosing volumes are provided by the organizers of the competition, i.e., the Directorate General of Armaments (DGA: Direction Générale de l'Armement). Provided with raw data, they allow the evaluation of the positioning performances. This dataset is available on the data repository https://doi.org/10.5281/zenodo.4290789.

Keywords

Pedestrian navigation, inertial sensors, GNSS, indoor & outdoor positioning, Infra-Red stereo

Specifications Table

Subject	Signal Processing in multisensory positioning
Specific subject area	Indoor-outdoor pedestrian and vehicle navigation with multiple sensor fusion techniques

Type of data	Table, Figure, Map, Video, Rosbag, from which the following sensor data can be extracted: - Ublox-M8N GNSS receiver: GPS and GLONASS data; - Realsense D435i: tri-axis accelerometer, tri-axis gyroscope, compressed infrared stereo images, compressed depth image; - Xsens MTi-300: tri-axis accelerometer, tri-axis gyroscope, tri-axis magnetometer, barometer, thermometer; - PERSY: tri-axis accelerometer, tri-axis gyroscope, tri-axis magnetometer, GNSS receiver: GPS and GLONASS data
How data were acquired	The data were collected with several sensors (inertial sensors and GNSS receivers) attached to different parts of the subject's body. The scenario is designed to simulate the firefighters' mobility during an intervention.
Data format	Raw data: Raw GNSS data; Raw inertial and magnetic data PERSY Calibrated inertial data Xsens Analyzed/Filtered data: the final position estimates computed by the CyborgLOC team during the competition.
Parameters for data collection	The activities include walking, running, stair-climbing, side-walking, crawling, passing above/below obstacles, carrying a stretcher, ladder climbing, etc. The travelled environments include indoor, outdoor, urban canyons. The indoor part contains different stair levels: from the underground up to the 6th floor.
Description of data collection	The data was collected in the framework of the indoor/outdoor positioning competition MALIN, which aims at designing a real-time positioning system for the military or the first response emergency services.
Data source location	City/Town/Region: Blois Country: France
Data accessibility	Repository name: Zenodo Data identification number: 10.5281/zenodo.3785045 Direct URL to data: https://doi.org/10.5281/zenodo.4290789

Value of the Data

- This multiple sensor dataset is collected during an indoor/outdoor positioning competition in a challenging scenario of firefighter intervention. The sensors are mounted on different parts of the subject's body. The high accurate ground truth is partly provided, which allows evaluating the performance of positioning algorithms.

- The following people may benefit from this dataset: Researchers who work in the domain of pedestrian positioning, data scientists who are interested in human activity classification or pattern recognition, and biomechanics researchers working on human gait analysis, etc.

- The performances of positioning algorithms applied to this dataset could be a benchmark of the current existing positioning techniques. The scenario design methodology is also useful for future experiment design.

- The various travelled environments and complex activities of the subject make the dataset full of challenges for positioning. The maps and evaluation metrics are also provided, which allows different users to assess their positioning algorithms.

1. DATA DESCRIPTION

1.1 General description and structure of the repository

The dataset contains inertial signals, infrared images, depth images, Global Navigation Satellites System (GNSS) measurements, pressure, temperature and magnetometer measurements that were collected during the annual competition of the indoor positioning challenge MALIN (MAîtrise de la Localisation INdoor). The same subject, equipped with the test setup, collected the data in two different scenarios: a 1500 m outdoor/indoor reference scenario and 1300 m indoor/outdoor evaluation scenario. The dataset includes also the ground truth of stationary points and enclosing volumes computed by the competition organizers, i.e., the Directorate General of Armaments (DGA) and the French National Research Agency (ANR). The final outputs estimated by the CyborgLoc competition team are also provided.

The different sensors, embedded in the prototype, are coupled and coordinated by the Robot Operating System (ROS) via its powerful communication infrastructures (e.g.: service, message, topics, etc.). The data format is the common ROS data/message type, which is recorded in bag files using the "rosbag" tool. All data samples are timestamped using the ROS standard message "Header", including a timestamp divided into secs and nsecs. Data are listed by topics in the bag file. A conversion tool (https://github.com/4g-group/malin_data_processing_tools) is provided. It allows merging Rosbags as well as converting Rosbag files into Common Separate Vector (CSV) files.

The complete dataset is shared via the Zenodo repository (https://doi.org/10.5281/zenodo.4290789). The data is sorted by scenario into two folders, i.e., "E_scanario_data" and "R_scenario_data", containing the data collected respectively during the Evaluation scenario and the Reference scenario. The structure inside each scenario folder is the same. It includes the following sub-folder: 1_Sensors_readings, 2_Sensors_calibration_and_configuration, 3_Ground_truth, 4_CyborgLocTeam_output. The content of each sub-folder is detailed in Section II: Experimental Scenarios of this paper.

1.2 Experimental setup

As shown in Fig. 1, the experimental setup includes the following sensors: one Ublox NEO-M8N GNSS receiver located on the right shoulder of the subject, a Realsense D435i stereo camera mounted on the left shoulder of the subject, three Xsens MTi-300 fixed respectively on the right shoulder, under the sternum and on the left foot of the subject and one PEdestrian Reference System (PERSY) on the right foot of the subject. Table 1 provides the technical specifications of the different sensors including the sampling frequency and the measurement units.

Fig. 1. Test setup for the acquisition of the data for the indoor competition challenge MALIN

Table 1. Technical specifications of the sensors used for building the dataset

Hardware Type	Embedded Sensors	Units	Dynamic Range	Sampling Frequency (Hz)
Ublox NEO-M8N	GPS-GLONASS (L1) receiver	N/A	N/A	5
Realsense D435i	tri-axis accelerometer	m/sec²	+/- 40 m/sec²	500
	tri-axis gyroscope	rad/sec	+/- 1000 °/sec	500
	IR stereo depth module	N/A	N/A	15
Xsens MTi-300	tri-axis accelerometer	m/sec² (calibrated)	+/- 50 m/sec²	50
	tri-axis gyroscope	deg/sec (calibrated)	+/- 450 °/sec	50
	Tri-axis magnetometer	a.u.*	+/- 80 uT	50
	Barometer	hPa	300-11000 hPa	50
	Thermometer	°C	N/A	1
PERSY	tri-axis accelerometer	m/sec²	+/-10 g	160
	tri-axis gyroscope	rad/sec	+/- 400 °/sec	160
	tri-axis magnetometer	mGauss	+/- 8.1 Gauss	160
	GPS-GLONASS (L1) receiver	N/A	N/A	5

*The output of the Xsens Magnetometer is in arbitrary units (a.u.), one a.u. is the magnetic field strength during calibration at xsens' calibration lab. This is approximately 40 uTesla (0.4 Gauss).

2. EXPERIMENTAL DESIGN, MATERIAL AND METHODS

2.1 Scenarios

The two scenarios took place respectively on the 25th (Evaluation scenario) and the 26th (Reference scenario) September 2019, at the Fire and Rescue Training Center (CFIS41) in Vineuil, France to simulate the situation of firefighters during interventions. As shown in Fig. 2, the site includes buildings with stairwells, corridors, rooms of different surfaces (from 3 to 50 squared meters), and floor heights with/without windows, basement, etc. The indoor path goes through several floors

(from the underground up to the 6th floor) with different changing floors means such as circular stairs, ladders and inclined planes.

Different motion modes and postures exist in each scenario. They correspond to the typical activities of firefighters such as lying down, crouching, crawling, jumping, sidestepping, carrying a load on the shoulders, crouching (1 knee on the ground) while pulling a load, evacuating a person by stretcher (pair), passing over obstacles of different heights, opening/closing solid/glass doors. Furthermore, environmental difficulties were also set up by the organizers to test the robustness of the localization systems involved in the competition. For example, they consist of walls with various or/and repeated patterns, uniform walls, strong luminosity, quick dimming of brightness, low brightness, mirrors, windows, Cold smoke, moving elements in the field of view (people, vehicles, objects, ...).

Fig. 2. An overview of the experimental site: the Fire and Rescue Training Center (CFIS41) for firefighters in Vineuil, France

During the data acquisition, the subject wore a firefighter uniform with rubber firefighting boots (without metal shells) equipped with all experimental sensors mentioned above. The subject carried an axe during the majority of the scenarios. Table 2 lists the 7 different phases presented in each scenario. The difficulties included in each phase are detailed in "Annex_1_X_scenario_description.pdf" inside each scenario folder.

Table 2. Chronological list of the seven phases of the experimental scenario

Phase Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Phase Type	Prepara-tion	Vehicle	Outdoor building approach	Known position	Indoor 1	Outdoor	Indoor 2	End
Duration	10 min	2-3 min	2–3 min	20 sec	15 min	1.5 min	15 min	3 min

- **Preparation**: The subject is equipped with the prototype and the whole system is turned on. Two calibration procedures are carried out for PERSY: a dynamic calibration for the magnetometer [1] and a static calibration to estimate the subject-dependent parameters to detect the stance phase. These parameters are provided in the "2_Sensors_calibration_and_configuration" file, detailed in section 2.3.
- **Vehicle**: As shown in Fig. 3, a typical firefighter vehicle is used to transport the subject from the preparation room to the test site. The subject gets into the vehicle and sits on a designated seat, which may differ from one scenario to another. The orientation of the seat relative to the longitudinal axis of the vehicle is unknown. The vehicle moves at a limited speed (< 30km/h) over a distance of approximately 400 m. During this phase, the prototype is activated and then connected to a GNSS Real Time Kinematic (RTK) receiver for possible

initialization. The lever arm between the two systems is not provided. When the vehicle arrives at the disembarkation point, the prototype is disconnected from the GNSS RTK receiver and the subject gets off the vehicle.

- **Outdoor building approach:** The subject walks about 150 m with different gaits and postures.
- **Known position**: The subject stops on a known point marked at the entrance of the building with a fixed orientation. A new initialization of the prototype is possible via a simulated GNSS receiver under the same conditions as the "Vehicle" phase. The simulated GNSS signal can be available or not depending on the entry point on the scenario.

Fig. 3. The subject is getting on the vehicle

- **Indoor 1**: The indoor path crosses several floor levels with various movements (walking, running, stair-climbing, side-walking, crawling, passing above/below obstacles, carrying a stretcher, ladder climbing, etc) as well as several difficulties previously described. The total duration of this phase is around 30 minutes.
- **Outdoor**: The subject walks a short outdoor distance between the two indoor phases. It is about 5 m away from the building.
- **Indoor 2**: Same as indoor 1.
- **End**: The scenario ends outdoors stationary on a marked waypoint.

2.2 Sensors reading

The raw data of all the sensors in the prototype is stored in the bag files of the folder "1_Sensor_readings" of each scenario in the Zenodo repository. For each scenario, two bag files can be found: the first one (i.e., X_scenario_data_camera_only.bag[1]) includes only the camera data and the second one (i.e., X_scenario_data_wo_camera.bag) includes all other sensors' data mentioned in Table 1 except the camera.

In the bag files, the raw data are saved in different topics of ROS messages. The list of these ROS topics as well as their full descriptions and example values are given in the annex file "Annex_2_RosTopic_description.pdf" in the subfolder "1_Sensor_readings" of each scenario folder. Several non-standard ROS messages were created by the CyborgLOC team to store measurements non existing in the standard ROS message library. This last information is also provided in the same folder as the bag files with the name "non_standard_ros_message".

[1] « X » represents one of the scenarios, which could be « E » for Evaluation scenario or « R » for Reference scenario.

To facilitate the use of our dataset under Rosbag format, a toolkit of python scripts named *MALIN Data Processing Tools* is provided on GitHub (https://github.com/4g-group/malin_data_processing_tools). It allows merging Rosbags, converting Rosbag files to CSV files as well as republishing camera's topics as decompressed data. Details about these processing tools could be found in the Readme file on the Github page.

2.3 Sensors calibration and configuration

The prototype's inertial sensors need to be calibrated to estimate and mitigate the stochastic and deterministic errors. The calibration parameters of each inertial sensor as well as the initial parameters are stored in the folder "2_Sensors_calibration_and_configuration". The following files are included:

- PERSY calibration and initial parameters are in the file "X_scenario_persy_calibration_data.bag[2]", which is detailed in Table 3.

Table 3. Description of PERSY calibration and initialization parameters

Parameters	Description
Magnetic Field	The reference magnetic field at the test site on the competition day calculated using the most recent World Magnetic Model (WMM)
Allan Variance parameters for accelerometer, gyroscope and magnetometer	Stochastic error parameters obtained by an Allan Variance Analysis with 14 hours of static acquisition at 160 Hz. Random walk component and bias instability component are provided.
MagCalib	The output results of the dynamic calibration procedure using the algorithm in [1] to calibrate the magnetometer.
Thresholds (QSF, QSA, ZUPT)	The outputs of static calibration, which depend on the subject and are used to update the state vector in the Extended Kalman Filter (EKF) during the quasi-static phase of a walking gait cycle and quasi-static magnetic field periods. The algorithm's details can be found in [2].
Qbn	The initial attitude angles of PERSY in the quaternion form. Details about the conversion between Euler angles and the quaternion can be found in [2].

Raw data to calculate the above parameters are in the following files[3]:

- X_scenario_persy_dynamic_calibration_raw_data.bag
- X_scenario_persy_static_calibration_raw_data.bag

Except for the stochastic error parameters mentioned above, the determinist error parameters for PERSY accelerometer are also provided in the file "PERSY_calib_determinist_error.txt", which aims at correcting axis misalignment and offset.

- Realsense D435i camera calibration parameters are in the following files, which are detailed in Table 4.

[2] « X » represents one of the scenarios, which could be « E » for Evaluation scenario or « R » for Reference scenario.

[3] Due to an unexpected situation of the evaluation scenario, the dynamic camlibration for the magnetometer was not realised during the prepare phase. The parameters used are the ones estimated the day before. Thus no raw data of dynamic calibration is provided in the dataset for the evaluation scenario.

- "X_scenario_camera_calibration_data_allan.yaml"
- "X_scenario_camera_calibration_data_calibr.yaml".

Table 4. Description of Realsense D435i calibration parameters

Parameters	Description
Allan Variance parameters for accelerometer, gyroscope	Stochastic error parameters obtained by an Allan Variance Analysis with 12 hours of static acquisition at 400Hz. Random walk component and bias instability component are provided.
Intrinsic parameters for Infra-red cameras parameters (fx, fy, cx and cy)	The imagers we use are the two infrared imagers. They are cameras with a wide angle of view, however data provided are rectified video streams. Therefore, we model our camera with the pinhole model and estimate the intrinsic parameters of the two cameras and the matrix estimating the rotation/translation between these two reference frames thanks to a target called Aprilgrid [3] and the method proposed in [4].
Extrinsic parameters between IMU and Cameras (imu_T_cam0 and imu_T_cam1)	These parameters provide spatial transformation information between the imagers and the inertial unit, as well as the time difference between the two types of sensors, estimated by the maximum likelihood method in continuous time [5,6].

The measurements of Xsens sensors are already calibrated so the calibration parameters are not provided. Configuration files for Realsense D435i and Ublox M8N GNSS receiver are also provided in the sub-folder "2_Sensor_calibration_and_configuration/configuration". Complementary information or parameters can be found if needed.

2.4 Ground Truth

The organizers of the challenge MALIN have estimated reference coordinates (stationary points) and reference volumes (enclosing volumes) to assess the performances of the competing positioning technologies. These reference coordinates considered as the ground truth are also provided in the dataset, in the folder "3_Ground_truth" under each scenario folder.

The reference points and volumes were estimated with a Differential GNSS (DGNSS) post-processing coupled with theodolite records. Assisted by differential corrections provided by permanent base stations belonging to the French networks RGP, DGNSS receivers were used to estimate accurate absolute reference Points of Interest (POI) outdoors (on the ground or the roof of the buildings). Once the maps of buildings were correctly positioned, the next step consisted of surveying indoor POIs using a theodolite, which is an accurate optical measurement system measuring distances and angles between its position to a POI where a target-mirror is setup. Starting outdoors, on a known reference coordinates point, this process constructs step-by-step all needed indoor POI coordinates. The positioning error is controlled with a loop closure error computed on the same starting/ending surveying point.

Accurate geo-referenced coordinates (5-10 cm) with Mean Sea Level (MSL) altitude associated with a predefined reference orientation are provided for each reference stationary point. During the test scenario, as shown in Fig. 4, the subject stood still on each reference stationary point while facing an indicated direction. Both feet of the subject were joined together aligned along the indicated direction to avoid potential misalignment for the foot-mounted sensors.

An enclosing volume is a bounded and geo-referenced volume, such as a cylinder-type one (Fig. 5) or a room-type one (Fig. 6). During the test scenario, the subject performed different motions and specific trajectory patterns within a particular enclosing volume. It corresponds to moving in a bounded 3D space.

Fig. 4. Test scenario at a reference stationary point: The subject is with the red helmet looking at an indicated direction

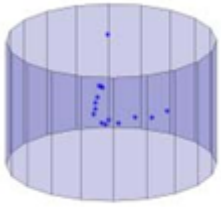

Fig. 5. Cylinder-type enclosing volume where the test person remained stationary

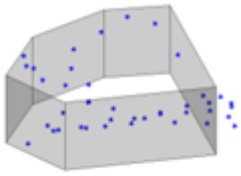

Fig. 6. Room type enclosing volume where the coordinates of the moving test person had to remain in this volume

The georeferenced maps of each floor (from -1 to 6) provided by the organizers are included in the sub-folder “maps” under the “3_Ground_truth” folder. These maps can be combined with the trajectories in kml format using the xml file “BASE_PLAN_CFIS41.xml”. To synchronize the ground truth data with the Coordinated Universal Time (UTC) timeframe, the UTC timestamps of the start and end instants of each stationary point are stored in the text file under the “Ground Truth” folder. Similarly, the entry and exist instants for each enclosing volume are given in UTC timeframe. The detailed descriptions of the .xml file and the text file can be found in the annex file “Annex_3_Ground_truth_file_description.pdf” in the “3_Ground_truth” folder.

Videos of the difficulties for each scenario are provided in the sub-folder “video”. These videos have been captured by the organizers using cameras that are synchronized at the same timeframe as the evaluation system.

3. EVALUATION METRICS

3.1 Proposed evaluation metrics

In the context of the competition MALIN, the organizers have used specific evaluation metrics to evaluate the positioning performances of each competitor’s localization system. For the convenience of the organizers, all the teams were required to provide the estimated positioning information at 5Hz through a unique PLOC format defined in the annex file “Annex_4_PLOC_description.pdf” under the subfolder “4_CyborgLocTeam_output” for each scenario.

The measurements used for the evaluation are the PLOCs stored between the entry and exit instants of each ground truth stationary point or enclosing volume. In the case of missing measurements, there is no interpolation and the errors are set at a constant level of 50m for the horizontal position errors, 15m for the vertical error and 20° for the orientation error. When evaluating the performance inside the enclosing volumes, a compensation of +1m is applied to the altitude calculated by each team's localization system to correspond to localization at the level of the subject's waist since each team was required to provide the altitude at the foot level of the subject.

The location accuracy score is determined based on two criteria: geometric and topological.

- **Location accuracy scoring - geometric criterion**

Geometric location errors are evaluated at the reference stationary points. The 2D geometric error (absolute horizontal errors) and vertical error are determined according to the following definitions.

The score of the 2D horizontal geometric criterion is determined by

$$Note_{2d} = \frac{130}{ns} \cdot \sum_{i=1}^{i=ns} \exp(-\frac{\varepsilon_i^{2D_{75\%}}}{3})$$

$\varepsilon_i^{2D_{75\%}}$ represents 75% horizontal positioning error at i^{th} reference stationary point in meter. *ns* represents the number of stationary points planned in the scenario.

The score for the vertical geometric criterion is determined by

$$Note_V = \frac{70}{ns} \cdot \sum_{i=1}^{i=ns} \exp(-\frac{|\varepsilon|_i^{v_{75\%}}}{3})$$

$|\varepsilon|_i^{75\%}$ represents 75% vertical positioning error at i^{th} reference stationary point in meters.
ns represents the number of stationary points planned in the scenario.

- **Location accuracy scoring - topological criterion**

Topological location errors are measured from the enclosing volumes provided in the ground truth file as well as the timestamp recorded by the organization staff when the subject passes by. It is based on the number of location data provided by the team's system contained in each enclosing volume between the times of entry and exit.

The score for the topological criterion is determined by

$$Note_T = 200 \cdot \frac{\sum_{i=1}^{V} N_{pm_i}}{\sum_{i=1}^{V} N_{pt_i}}$$

N_{pm_i} is the number of real measurements provided by the location system contained in the ith enclosing volume for the duration provided by the organization.
N_{pt_i} is the number of theoretical measurements contained in the ith enclosing volume at 5 Hz for the duration provided by the organization staff.
V is the total number of enclosing volumes for the scenario.

- **Orientation accuracy scoring**

At each reference stationary point, the subject is required to orient himself toward a predefined direction with the help of ground markers. The orientations provided by the location system are compared with the reference orientations.
To calculate a score for orientations, the average absolute errors using all orientation estimates are calculated in degrees (between 0° and 360°). Then, the score for the orientation criterion is determined by

$$\frac{1}{n}\sum_{i=1}^{n} |\varepsilon_i| \leq 10^{\circ} \rightarrow Note = 20\, points$$

$$\frac{1}{n}\sum_{i=1}^{n} |\varepsilon_i| > 10^{\circ} \rightarrow Note = 0\, points$$

n is the number of total PLOC outputs and $|\varepsilon|$ is the absolute value of the orientation's error in degrees.

A python script handy tool is provided on GitHub (https://github.com/4g-group/ploc_evaluation) to evaluate the localization results (in PLOC format) against the ground truth using the metrics mentioned above.

3.2 CyborgLOC Team output

The output of the CyborgLOC team is provided in the sub-folder "4_CyborgLocTeam_output" under each scenario folder. It includes a bag file with all the PLOC output, the position errors (e.g. Fig.7) and the orientation errors (e.g. Fig. 8) calculated using the ground truth as well as the estimated trajectories in kml format at each floor level. Fig. 9 shows the estimated trajectory at the level 0 by plotting the kml file with Google Earth.

CyborgLOC's positioning system is mainly based on the PERSY, which is a foot-mounted positioning device developed by GEOLOC Laboratory at the Gustave Eiffel University. Regarding the positioning algorithm used in PERSY, classical strap-down mechanization of inertial signals is applied while walking gait cycle characterization has been introduced to assist the computation with updates that occur during specific phases of the gait [2]. For example, during the stance phase of a walking gait cycle, zero velocity updates or zero angular rate updates are applied to mitigate the cumulative errors induced by the inertial sensors. During the competition, the GNSS signals from the Ublox NEO M8N receiver was employed in favorable tracking conditions to assist PERSY's positioning algorithm. This is realized by estimating the transformation parameters with a least-square algorithm between two synchronized point patterns, i.e., the GNSS trajectory in favorable tracking conditions and the PERSY trajectory [7].

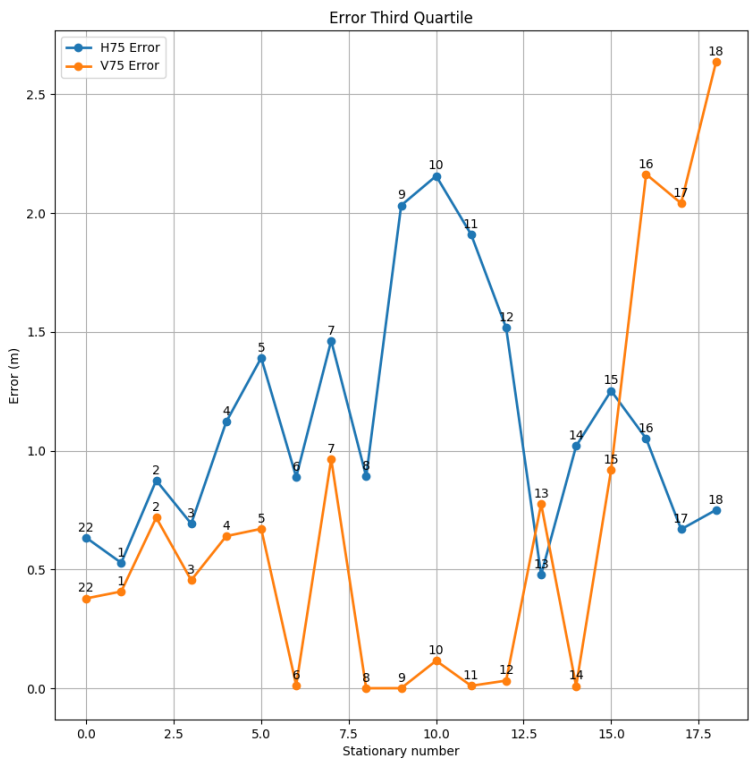

Fig. 7. Position errors of the CyborgLOC Team output for Evaluation scenario

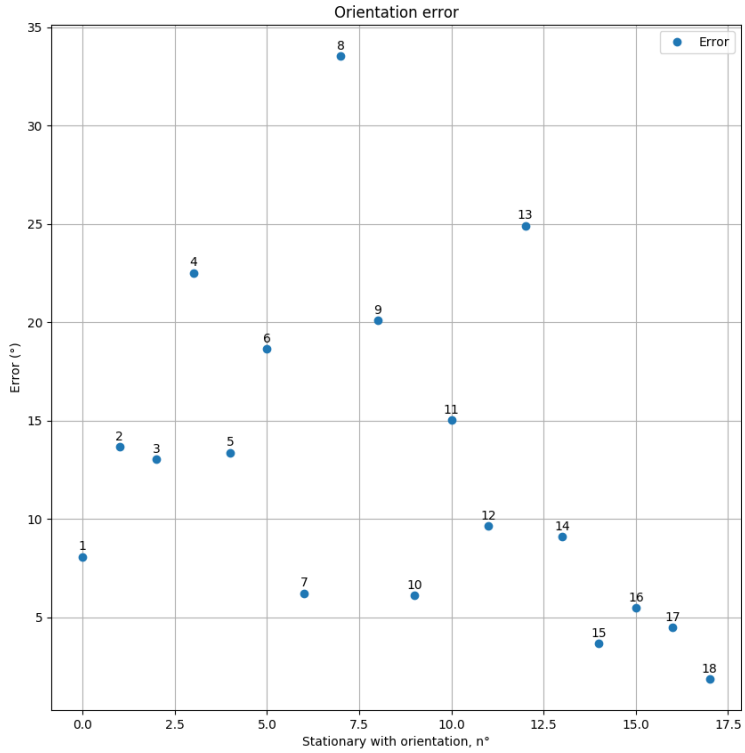

Fig. 8. Orientation errors of the CyborgLOC Team output for Evaluation scenario

Fig. 9. Trajectory estimated by CyborgLOC Team (Source: Google Earth)

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Ethics Statements

- Conflict of interest: The authors declare that they have no conflict of interest.
- Informed consent: Informed consent was obtained from all individual participants involved in the study.

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