Algorithm of effective data analysis in tracking applications

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Abstract

Geo-data is a specialized type of data that requires specific rules and algorithms for processing to yield reliable results. Efficient software solutions for geo-data processing require a structured and optimized data pipeline to ensure reliable data handling and computational performance. In the paper, an algorithm for effective geo-data processing is proposed. The algorithm represents the data processing workflow as a hierarchical structure comprising basic (primary), multisensor, trajectory, storage, and visualization levels. Basic data processing considers sensor level, which deals with data transformation and accuracy evaluation. Multisensor provides data fusion of the same parameters but measured from different sensors. Trajectory data processing considers data analysis, which provides calculation of secondary parameters like angles, velocities, accelerations, and timestemps. The relative location algorithm used in TopoJSON data format is considered an efficient trajectory coding for data storage based on minimization of required space. Proposed approach is unified and could be useful for various applications. Developed algorithm has been used in specific software for airplane trajectory data processing.

Keywords

Data analytics, sustainability performance, intelligent transport system, collaborative decision-making

1. Introduction

The sphere of tracking services is increasing every year. Measuring position of moving objects, processing, and visualization of trajectory are the key objectives of tracking applications. Multiple advantages make tracking functionally is an important component of modern enterprise, which connects with services connected to object data processing [1, 2]. Tracking plays crucial role in modern logistics and any intelligent transport system [3, 4]. Operation in a highly changeable environment requires searching for effective navigation and optimal solution of transportation task to minimize costs. Thus, it provides insuring of operational efficiency to improve route planning, minimize delays, and reduce fuel costs [5]. Tracking goods from the origin location to destination helps to avoid losses and improves reliability of services.

Modern safety and security services use tracking to know exact location of persons, vehicles, cargo, and equipment [6, 7]. Medical services could use special equipment to track patients who require specific therapy to control human performance [8, 9].

Tracking helps to ensure an effective decision-making process. Historical data helps to analyze the effective collaborative decision-making process for rote planning. Specific place tracking has in fitness and health to simple collect data about human activity and automatic training activity planning based on big data processing [10, 11].

Tracking includes four basic stages:

WDA'26: International Workshop on Data Analytics, January 26, 2026, Kyiv, Ukraine

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073
published 2026-02-01

CEUR-WS.org/Vol-4155/paper08.pdf

- measuring coordinates of remote object;
- sharing these data with central processing unit;
- trajectory data processing;
- data storage and visualization.

Any tracking application requires following all of these stages to get trajectory of moving object. It works in the same way for an advanced air traffic management system and for a simple activity monitor in a variety of Android/iOS fitness applications [12, 13]. The general problems of trajectory data processing are constantly identical across multiple applications.

In this paper, we consider general questions of tracking and provide a formalization of data analysis for tracking applications. An overall trajectory data processing structural scheme of data analysis is proposed to follow sensor-level data processing, trajectory data analysis and storage, multisensory data fusion, and visualization. The key element of the provided analysis is to propose a unified structure scheme for data analysis required to build an effective tracking application.

The paper has the following structure: Section 2 formalizes proposed process of tracking data processing; Section 3 includes an example of data analysis; finally, conclusions and future works are specified at the end of the paper.

2. Unified method of data analysis for tracking applications

This study considers a system comprising multiple objects whose positions are tracked, a digital data link, and a data processing server. The tracking of remote objects is based on the measurement of user locations. Each user (remote object) within the system is equipped with an electronic device connected to the server via a digital data link. The server performs data collection, processing, and analysis [14, 15].

In the common case tracking application is based on automated dependent surveillance (ADS), which means that position measuring is performed remotely on equipment associated with object that is under tracking [16, 17]. Remote electronic equipment should have a sensor for measuring position. In addition to position, any other parameters that characterize the tracking object could be measured and provided to the server [18]. Another surveillance technology could use object position measuring with a help of external sensors. As an example, active radars are widely used in aviation to measure location of airplanes. Radars provide ranges and azimuthal angles of each airplane that will be transformed to geographic coordinate system with the help of an exactly known radar location [19, 20]. Hyperbolic navigation is used for localizing the position of each user in a cell phone network. In this case network of access points of cellular service is used to measure the time delay of input signal to build a hyperbolic line of user's location [21, 22]. A remote user signal fixed by four ground stations made it possible to obtain location of user after solving navigation equation. The same hyperbolic localization method could be used in dense wireless data transferring networks (WiFi) [23, 24]. Classical surveillance is supported by a network of sensors that is used for remote object localization[25]. In this case, a system surveillance processing unit could provide localization data to a data processing server. Communication datalink to each remote user is not required, because location is measured in the surveillance network.

In a common case, tracking data follows four levels of processing:

- Sensor (or primary) level of data processing
- Multisensory data fusion;
- Trajectory data analysis and storage;
- Visualization.

All four levels provide a comprehensive approach to data analysis. At each of these levels, different operations with data are performed. Also, each of these levels has defined input and output data and could be processed in different physical equipment based on system architecture.

2.1. Sensor (or primary) level of data processing

This level provides coordinates of object measurements and performs initial data processing to improve confidence level of provided data. At the output of this level coordinates of user are obtained. Most tracking applications are based on ADS technology with the Global Navigation Satellite System (GNSS). GNSS is one of the cheapest sensors and provides the most accurate position data. These data are already presented in geodetic coordinates (longitude, latitude, and altitude). In case GNSS outage inertial navigation system (INS) could be initiated in intelligent transport system [26, 27].

INS uses measurements of acceleration and angular velocities to calculate paths along the axis of reference frame and finally calculates position. But, due to additive noise, errors of positioning accumulate errors of sensor measuring at each step. This made INS accuracy dependent on operation time. Performance of INS highly depends on sensor type used for acceleration measurement. Coriolis force-type gyroscopes are the most popular nowadays, which are cheap but provide low precision. Optical gyros (laser or fiber optic) provide highly accurate data, but price and size make such sensors available only for advanced tracking applications.

Also, object position could be measured in modern, commercially available communication networks. Position of user could be available in communication module. Different technologies could be used for position measuring but position calculation requires available data about network nodes' geometry. In some cases, a Received Signal Strength (RSS) method could be used, which is based on measuring the strength of a received radio signal transmitted from each node of communication network [28]. RSS is based on a path-loss model, which calculates distance from user to each node by measuring signal strength. The trilateration method could be used to identify object position based on measured ranges and coordinates of ground stations [29]. Due to the low altitude of communication nodes placement and significant influence of multipath effect performance of obtained data could be significantly different based on network configuration and technology used.

Also, there are several methods of position identification based on a visual sensor. In this case, a camera is used to obtain a photo, which is later compared with an archive of photos generated from the map. The same idea is used in Simultaneous Localization and Mapping (SLAM) algorithms, which perform multiple distance measurements from object to environment to make a map of environment [30, 31]. Obtained map of environment is later used for moving object localization based on measured ranges. In some military applications radar picture of the environment or magnetic field data could be used to identify user's location in the same manner as SLAM technology.

Some sensors, like radars, could provide measuring object coordinates in a local polar reference frame. Radar uses an active interrogation signal and processes reflected (or reply) signal to get the time delay. Due to the constant speed of radiowaves propagation in the atmosphere range to the object (R) could be measured. Azimuthal angle (A) is coinsides with antenna direction (or phase shift in antenna array). Azimuthal-range polar data could be transformed to the North-East local frame and then to the geodetic coordinate system. Coordinates in polar to cartesian reference frame are calculated as follows:

$$x_{NED} = Rcos\left(A\right), \tag{1}$$

$$y_{NED} = Rsin\left(A\right), \tag{2}$$

where x_{NED}, y_{NED} are coordinate of object in the North-East local frame, where x is directed to the North.

Next coordinates from the North-East local frame should be transformed to latitude and longitude through the Earth-Centered, Earth-Fixed (ECEF) frame:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} (N_0 + h_0)\,cos\left(\lambda_o\right) cos\left(\varphi_o\right) \\ (N_0 + h_0)\,cos\left(\lambda_o\right) sin\left(\varphi_o\right) \\ \left(N_0\left(1 - e^2\right) + h_0\right) sin\left(\lambda_o\right) \end{bmatrix} + \begin{bmatrix} -sin\left(\lambda_o\right) cos\left(\varphi_o\right) & -sin\left(\varphi_o\right) \\ -sin\left(\lambda_o\right) sin\left(\varphi_o\right) & cos\left(\varphi_o\right) \\ cos\left(\lambda_o\right) & 0 \end{bmatrix} \begin{bmatrix} x_{NED} \\ y_{NED} \end{bmatrix}, \tag{3}$$

$$N_0 = \frac{a}{\sqrt{1 - e^2 sin^2\left(\lambda_o\right)}}, \tag{4}$$

where λ_o,φ_o, h_0 are latitude, longitude, and altitude of radar location; e is a first eccentricity; a is semi-major axis.

For case WGS84 $e^2 = 0.00669437999014$ and $a = 6378137m$. User coordinates could be estimated by Bowring's formula as follows:

$$\varphi = atan2\left(y, x\right), \tag{5}$$

$$\lambda = atan2\left(\left(z + \sqrt{a^2\left(1 - e^2\right)\frac{a^2 - b^2}{b^2}}sin^3\left(\theta\right)\right), \quad \left(\sqrt{x^2 + y^2} + ae^2cos^3\left(\theta\right)\right)\right), \tag{6}$$

where $atan2\left(x, y\right)$ is a two-argument arctangent mathematical operation used in computing that calculates the angle of a vector in the correct quadrant of the Cartesian plane.

Error of position detection is usually represented as standard deviation error [32], which for case of a polar sensor is estimated as follows:

$$\sigma_{xy}^2 = \sigma_R^2 cos\left(A\right)^2 + R^2\sigma_A^2 sin\left(A\right)^2 + \sigma_R^2 sin\left(A\right)^2 + R^2\sigma_A^2 cos\left(A\right)^2. \tag{7}$$

where σ_R is the standard deviation error of range measuring in radar; σ_A is standard deviation error of azimuthal angle measuring.

At the end of sensor level, coordinates of user are obtained (preferably in latitude and longitude). Then these data are transmitted to the data processing server with the help of a data link. It should be noted that each coordinate should be accompanied by standard deviation error of positioning σ_{xy}. Data transmission in modern wireless communication networks follows to access point where the next data should be transferred by any TCP/IP protocol in a wired Ethernet network.

A simple API with GET or POST data transfer method could be used for data transmission to the server side. Transferred data could be received and processed with the help of server-side languages like PHP. PHP script could validate HTTPS requests, check the correctness of transmitted data, and store it in the internal database. Commonly, a MySQL database is widely used. Data transmission could be protected from unauthorized access with a transmitted key in HTTPS header, which could also be used to identify user. HTTPS easily protects data privacy during message traveling in the network. Transferred key in the header of HTTPS reduces server workload due to processing only valid requests. The following minimum data should be stored:

- Identification code of object or sensor;
- Coordinates in latitude, longitude (altitude);
- Datetime stamp of data measuring on device (different from time of recording in database);
- Accuracy in the form of standard deviation error of positioning σ_{xy} in [m].

Any additional data could be stored in association with this record. Also, it should be noted that storing this data is temporary until the end of trajectory is reached. At the end of tracking this trajectory should be processed and saved in another database in the form of a path.

2.2. Multisensor data fusion

Multisensor data processing is performed at the server side based on input data from different sensors fixed in internal database. In the case of only one input sensor, this level of data processing could be omitted.

In particular systems, several sensors could measure position of tracked object. For example, in civil aviation, position is measured on-board with GNSS and shared by ADS, but also position could be measured by ground radars, and a multilateration system which utilizes hyperbolic navigation. Thus, in the general case, a number of sensors could provide coordinates of tracked object. Coordinates provided by each sensor will be different due to the different noise levels of sensors. Also, most sensors are not synchronized, therefore, results of measurement could be obtained at different times with different rates of data updating.

Therefore, multisensor data processing should start from time synchronization of all available datasets stored separately by each sensor. Polynomial function of high rank or a linear regression model with nonlinear spline functions could be used for data interpolation. Interpolated data to unique timestamps based on input rate forms a sequence of synchronized measurements for further data fusion.

Algorithms of data fusion usually work with Cartesian frames, thus, before fusion, it could be more accurate if all data series were transformed to ECEF or a local North-East Cartesian reference frame.

The data fusion is performed by Maximum Likelihood Estimation (MLE). MLE leverages the strengths of redundant information to achieve improved accuracy and reduced uncertainty area compared to using individual data sources alone. The likelihood function is used to represent the probability of observing all the collected data points, given the unknown parameter that is required to estimate. MLE provides data fusion based on minimization of the uncertainty area as follows:

$$X = \frac{\sum_{i=1}^{n} x_i \sigma_x^{-2}}{\sum_{i=1}^{n} \sigma_x^{-2}}, \tag{8}$$

$$\sigma_{pos}^2 = \frac{1}{\sum_{i=1}^{n} \sigma_{xy}^{-2}}, \tag{9}$$

where n is the number of sensors used; σ_{pos}^2 is the standard deviation error of obtained position of the object.

2.3. Trajectory data analysis and storage

After data fusion, a raw trajectory is obtained, which includes a sequence of coordinates and timestamps. At the trajectory data analysis level, three common tasks should be performed:

- Filtering errors;
- Calculation of trajectory parameters;
- Data storage as a separate trajectory.

The accuracy of trajectory data could be improved based on known model of a moving object. Specialized trajectory filters analyze all available data to build a model of user movement. This model is used to predict future user location, which is fused with real measurements. This is the general idea of any trajectory filter. The most commonly used filters are: Kalman filter, $\alpha - \beta$ filter, $\alpha - \beta - \gamma$ filter, and $\alpha - \beta - \gamma - \eta$ filter.

Kalman filter model has a clear structure, which includes three main components: model of movements, model of sensor, and model of environment. This three-component structure creates an adaptive approach for various model implementations. Tracking $\alpha - \beta$ filter assumes movement with constant speed. The $\alpha - \beta - \gamma$ filter could be applied to objects that are moving with acceleration. Tracking $\alpha - \beta - \gamma - \eta$ filter considers objects that are moving with jerk.

The most useful $\alpha - \beta - \gamma$ filter has the following model:

$$X_i^e = X_{i-1}^F + V_{i-1}\left(t_i - t_{i-1}\right) + \frac{A_{i-1}\left(t_i - t_{i-1}\right)^2}{2}, \tag{10}$$

$$X_i^F = X_i^e + \alpha(X_i^m - X_i^e), \tag{11}$$

$$V_i = V_{i-1} + A_{i-1}\left(t_i - t_{i-1}\right) + \beta\frac{(X_i^m - X_i^e)}{t_i - t_{i-1}} \tag{12}$$

$$A_i = A_{i-1} + \gamma\frac{2(X_i^m - X_i^e)}{\left(t_i - t_{i-1}\right)^2}, \tag{13}$$

where X_i^F is matrix of filtered values; X_i^e is matrix of extrapolated data; V_i is matrix of velocities; A_i is matrix of accelerations; α is coefficient of guidance by parameter; β is coefficient of guidance by velocity; γ is coefficient of guidance by acceleration.

The $\alpha - \beta - \gamma$ filter provides reliable noise reduction in the results of trajectory measurements, the exact value of which depends on object movement behavior. Practical results of $\alpha - \beta - \gamma$ filter implementation in the aerospace domain could provide up to double noise level reduction.

Filtered trajectory data could be applied to trajectory parameter estimation. Ground velocity could be easily calculated from a sequence of coordinates:

$$V_i = \sqrt{\frac{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}{(t_i - t_{i-1})^2}}, \tag{14}$$

where x, y are coordinates of object in the local North-East reference frame; t is the time stamp of coordinates measurement.

Heading angle could also be calculated for each leg of available trajectory and total length and time of trajectory.

After trajectory is completed, it should be saved in the database. The raw sequence of latitude and longitude is not optimal due to a significant level of redundant information. The optimal data format for trajectory archiving is TopoJSON. TopoJSON format includes an initial reference point specification. All other trajectory is represented as a path of object coordinates changes at each point of the trajectory.

2.4. Visualization

There are different tools that could be used for data visualization. Most tracking applications require 2D visualization of tracking object only, which uses only latitude and longitude data. Such tracking applications consider user movement on the surface of Earth. In case of flying object tracking parameter of altitude is important, therefore, 3D visualization could be helpful. Such a visualization tool usually uses a virtual scene which is built based on textures and accurate relief model. Artificial constructions, buildings, could be used in such a visualization. 3D visualization in a virtual environment is suitable for studying some particularities that may happen during tracking object study, but it is not useful for trajectory studies.

Most trajectory studies require having access to the whole trajectory visible in the area of software indication, given, in particular map projection. Map projections are the best when geo-data has to be visualized on a 2D screen. In the case of an aerial vehicle, parameter of altitude could be important, thus vertical profile is plotted in a separate figure. To improve situation awareness, of visualization map or relief data could be additionally used for trajectory visualization in 2D.

In the case of 3D visualization, any virtual environment could be useful. Most commercially available environment for 3D has a way for data migration via API or by a simple text file. For example, X-Plane software could be used in two modes: point-by-point visualization of objects with co-located texture of tracking objects. But also, a whole trajectory could be used in flight data recorder simulation mode.

2D trajectory visualization could also be done in a different environment. MATLAB with the mapping toolbox provides a variety of map projections for visualization. Fully integrated formulas of data transformations between different projections made MATLAB useful for post-tracking surveillance data processing and analysis.

A reach visualization capability is proposed in JavaScript for web-based applications. Rapid development in hardware during the last decade has made it possible to solve complicated visualization tasks in GPU of ordinary computers. Browser-based and open-code scripts are very popular today in many applications, including cartographic and tracking. Google Maps and OpenStreet maps are the most popular solutions. Leading libraries for data visualization in these maps include MapBox, OpenLayers, and Leaflet. One of the main points of web applications with JavaScript is cross-platform applications, which significantly increases number of users and reduces costs in overall multi-system design. In addition, an adaptive interface with CSS made the system design suitable for best practices.

For cases of geo-data visualization, a Hexagonal Hierarchical Spatial Indexing system (H3) is used. H3 library has a JavaScript version and provides rapid data processing for geo-data analysis [33]. The key feature of H3 is using unique indexes instead of geographic coordinates. In H3 coordinates of point

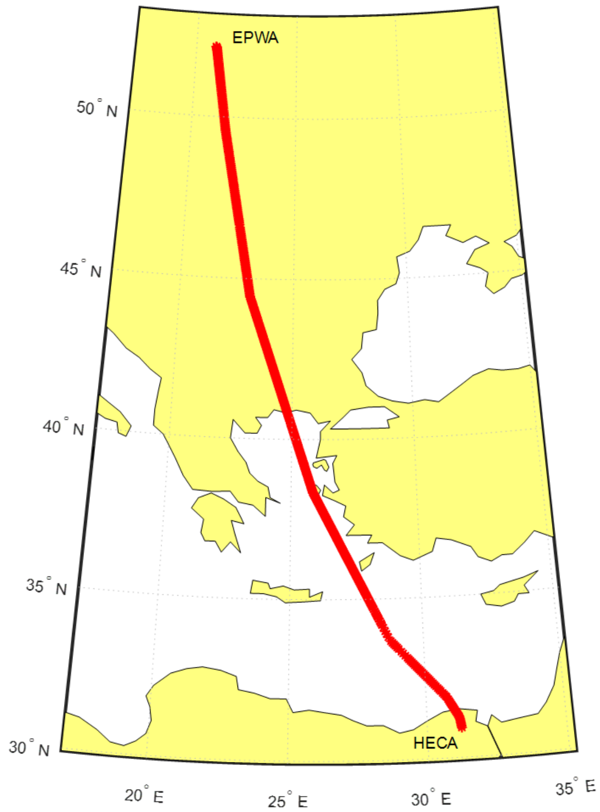

Figure 1: Raw trajectory data of LO149 in equidistant cylindrical projection.

in geographic coordinates are replaced with the index (or unique address) of cell. The size of cell could be tuned based on resolution level from a very small to a very big one. These transformations made it possible to significantly increase of any geo-data processing due to operation in the space of addresses, which does not require coordinate transformation between reference frames.

H3 is widely used in several parameter distribution studies across the globe, like air pollution, sea level studies, traffic density, and others. Also, H3 is suitable for trajectory representation of any moving object, its collaborative analysis, and delay study.

Based on the given analysis of available solutions for data visualization, it could be concluded that web web-based application PHP- MySQL- HTML- CSS-JavaScript, is the most suitable technology for any trajectory data visualization in 2D. A mapping tool for JavaScript could be different based on the required function and overall software budget.

3. Numerical demonstration

The proposed algorithm of geo-data visualization has been verified with the trajectory data of civil flight LO149, which connects Warsaw Frederic Chopin airport (EPWA) and Cairo International airport (HECA) performed on December 24, 2025. Flight operated by LOT Polish Airlines with airplane type Boeing 737 MAX 8. Airplane left EPWA at 17:54 CET and landed in HECA at 22:31 EET. Flight duration was 3 h 37m. The trajectory data set includes 385 points of latitude, longitude, altitude, and time. The dataset was obtained from a collection of digital messages transmitted on the 1090MHz channel under Automatic Dependent Surveillance-Broadcast (ADS-B) technology [34]. ADS-B data includes non-synchronous messages, due to some messages could be lost during transmission.

Geometry of LO149 trajectory in the Equidistant Cylindrical projection is shown in Figure 1. Results of trajectory transformation to the local NED reference frame are given in Figure 2. Coordinates of EPWA airport are used as a reference point for NED frame. Surveillance data obtained with ADS-B

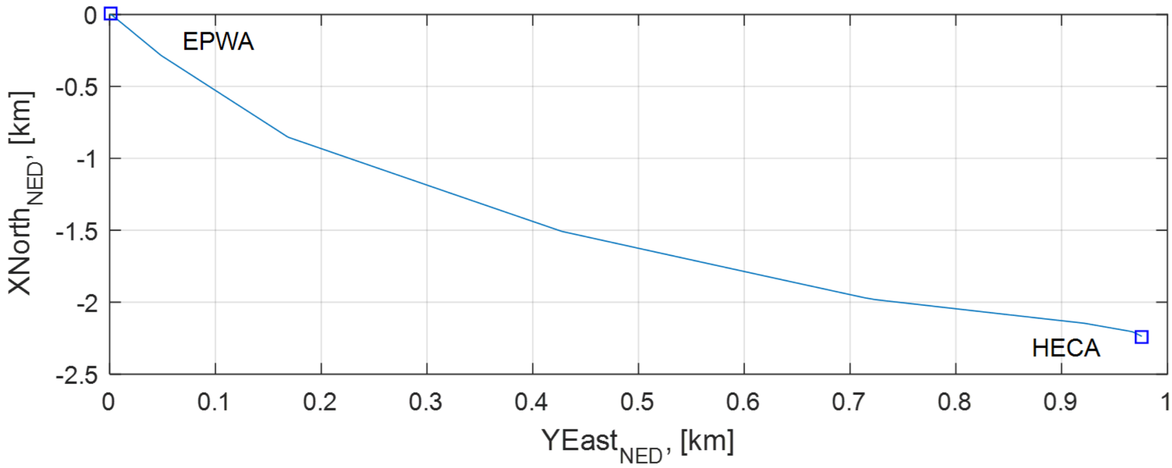

Figure 2: Raw trajectory data of LO149 in local NED reference frame.

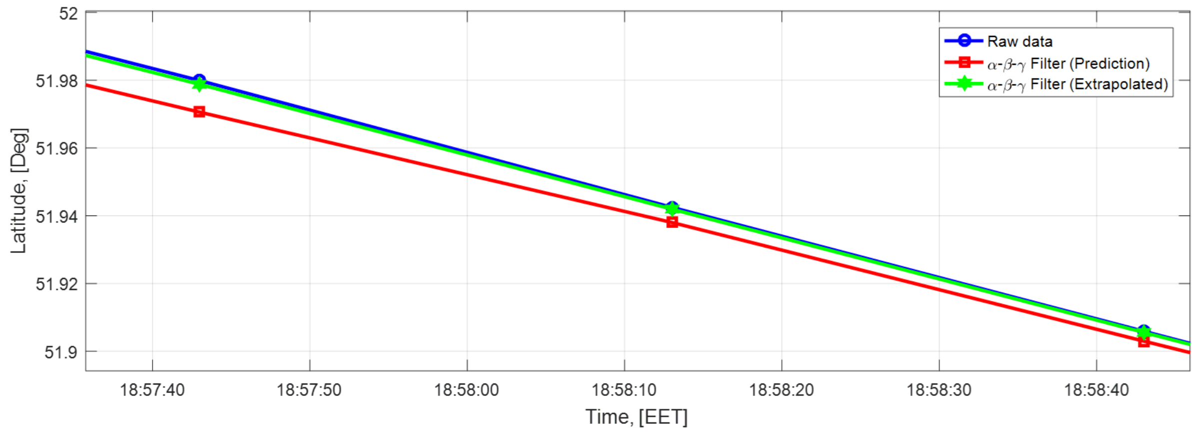

Figure 3: Latitude of LO149 filtering with $\alpha - \beta - \gamma$ trajectory filter.

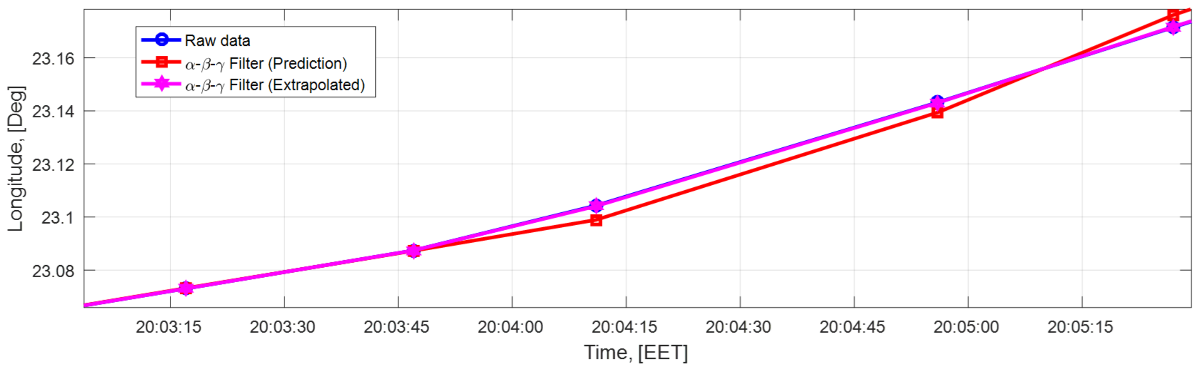

Figure 4: Longitude of LO149 filtering with $\alpha - \beta - \gamma$ trajectory filter.

technology includes high-precision coordinates of airplane position measured by on-board GNSS sensor. Tracking filter reduces error action and smooths the trajectory. The $\alpha - \beta - \gamma$ filter is used in NED frame recalculated filtered and predicted data by latitude and longitude are shown in Figures 3 and 4. Based on filtered data, the trajectory parameters should be calculated. True heading angle and ground speed are calculated based on the horizontal components of NED frame for trajectory data of LO149. Results for heading and speed are given in Figures 5 and 6 correspondingly. Filtering is an important stage that should be applied during processing of trajectories of dynamic objects. Dynamic objects could

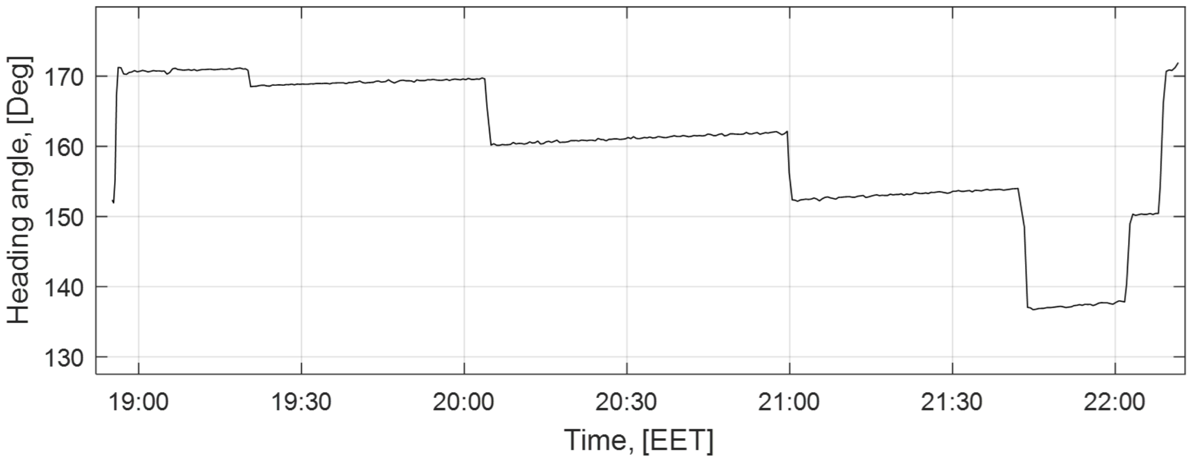

Figure 5: Heading of LO149 trajectory.

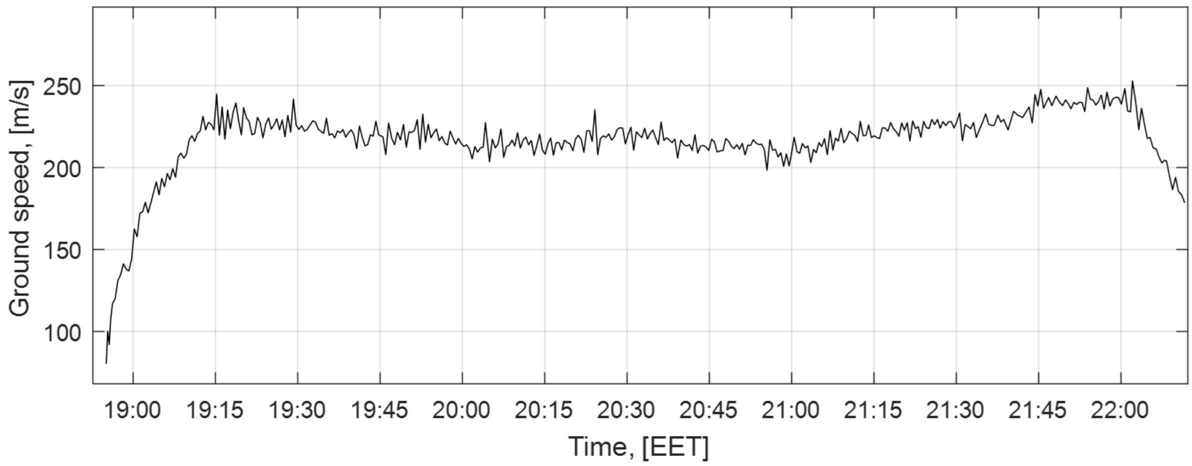

Figure 6: Ground speed of LO149.

not change trajectory immediately and continue movement due to the action of particular forces on objects with mass. Tracking filters help to recover the dynamic model and use it in trajectory prediction.

Calculated heading angle and ground speed could be classified as “secondary” parameters due to their recalculation from trajectory. These parameters help to analyze properties of a moving object, which could be useful in triggers or convolution networks to analyze a state of a moving object and support collaborative decision-making.

All stages of data processing are important to get a reliable data set for further storage and visualization. However, based on input data and system configuration, stages could be switched between each other.

4. Conclusions

Geo-data has special properties that require to use of specific rules for data processing and storage. End-user deals with a geographic coordinate system specified by latitude and longitude however, data storage and processing require a Cartesian frame. Results of paper study present a clear structure that includes three levels of geo-data processing: primary, multisensory, and trajectory. Each of these levels has a specific set of operations that are required to process to improve data continuity and accuracy. Effective data storage could be provided only by using a local NED reference frame and a sequential process of coordinate accumulation available in the Geo-Topo relative location algorithm.

Data visualization is another important stage which requires data transformation between reference frames from format in which data is stored to some format in which data is processed and finally to frame of a particular map projection used for data representation on at flat screen.

Results of structured geo-data processing could be applied to different sorts of data, but data should include a sequence of points that are result of a particular object movement in the space.

All stages of data processing should be applied to get a valid dataset for correct visualization and to extract additional informative parameters based on the data.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

References

[1] S. Ko, J. Lee, D. An, H. Woo, et al., Menstrual tracking mobile app review by consumers and health care providers: quality evaluations study, JMIR mHealth and uHealth 11 (2023) e40921.

[2] L. Torres-Ronda, E. Beanland, S. Whitehead, A. Sweeting, J. Clubb, Tracking systems in team sports: a narrative review of applications of the data and sport specific analysis, Sports Medicine-Open 8 (2022) 15.

[3] D. G. Dong, Design and development of intelligent logistics tracking system based on computer algorithm, International Journal for Applied Information Management 3 (2023) 58–69.

[4] M. Elsanhoury, P. Mäkelä, J. Koljonen, P. Välisuo, A. Shamsuzzoha, T. Mantere, M. Elmusrati, H. Kuusniemi, Precision positioning for smart logistics using ultra-wideband technology-based indoor navigation: A review, Ieee Access 10 (2022) 44413–44445.

[5] I. Ostroumov, O. Ivashchuk, N. Kuzmenko, Preliminary estimation of war impact in ukraine on the global air transportation, in: 2022 12th International Conference on Advanced Computer Information Technologies (ACIT), 2022, pp. 281–284. doi:10.1109/ACIT54803.2022.9913092.

[6] S. Bondarenko, A. Bratko, V. Antonov, R. Kolisnichenko, O. Hubanov, A. Mysyk, Improving the state system of strategic planning of national security in the context of informatization of society (2022).

[7] S. Bondarenko, O. Makeieva, O. Usachenko, V. Veklych, T. Arifkhodzhaieva, S. Lernyk, The legal mechanisms for information security in the context of digitalization, Journal of Information Technology Management 14 (2022) 25–58.

[8] A.-K. Schalkamp, K. J. Peall, N. A. Harrison, C. Sandor, Wearable movement-tracking data identify parkinson's disease years before clinical diagnosis, Nature Medicine 29 (2023) 2048–2056.

[9] K. Azbeg, O. Ouchetto, S. J. Andaloussi, Blockmedcare: A healthcare system based on iot, blockchain and ipfs for data management security, Egyptian informatics journal 23 (2022) 329–343.

[10] K. Chakate, G. Giri, S. S. Gonge, A. Deshpande, Y. Pawade, R. Joshi, Covicare: Tracking covid-19 using powerbi, in: 2022 8th International Conference on Signal Processing and Communication (ICSC), IEEE, 2022, pp. 74–78.

[11] M. Paul, L. Maglaras, M. A. Ferrag, I. Almomani, Digitization of healthcare sector: A study on privacy and security concerns, ICT express 9 (2023) 571–588.

[12] E. L. Zheng, Interpreting fitness: self-tracking with fitness apps through a postphenomenology lens, Ai & Society 38 (2023) 2255–2266.

[13] R. kalidindi Raja, et al., Fitness tracking system, International Journal of HRM and Organizational Behavior 12 (2024) 224–234.

[14] R. Raman, M. Kaul, R. Meenakshi, S. Jayaprakash, D. R. Devi, S. Murugan, Iot applications in sports and fitness: Enhancing performance monitoring and training, in: 2023 Second International Conference On Smart Technologies For Smart Nation (SmartTechCon), IEEE, 2023, pp. 137–141.

[15] K. Yang, S. A. McErlain-Naylor, B. Isaia, A. Callaway, S. Beeby, E-textiles for sports and fitness sensing: current state, challenges, and future opportunities, Sensors 24 (2024) 1058.

[16] R. Reda, F. Piccinini, G. Martinelli, A. Carbonaro, Heterogeneous self-tracked health and fitness data integration and sharing according to a linked open data approach, Computing 104 (2022) 835–857.

[17] H.-M. Kim, I. Cho, M. Kim, Gamification aspects of fitness apps: Implications of mhealth for physical activities, International Journal of Human–Computer Interaction 39 (2023) 2076–2089.

[18] V. Ivannikova, M. Zaliskyi, O. Solomentsev, I. Ostroumov, N. Kuzmenko, Statistical data processing technologies for sustainable aviation: A case study of ukraine, Sustainability 17 (2025). URL: https://www.mdpi.com/2071-1050/17/13/5781. doi:10.3390/su17135781.

[19] A. K. Kowshik, D. Vetrivel, G. Thiagarajan, S. Gurugopinath, Interactive multiple model-based high-resolution tracking in polar form for millimeter-wave radars, in: 2024 National Conference on Communications (NCC), IEEE, 2024, pp. 1–6.

[20] Y. Xu, Q. Huang, S. Shen, H. Yin, Incorporating point uncertainty in radar slam, IEEE Robotics and Automation Letters (2025).

[21] I. Ostroumov, N. Kuzmenko, Configuration analysis of european navigational aids network, in: 2021 Integrated Communications Navigation and Surveillance Conference (ICNS), 2021, pp. 1–9. doi:10.1109/ICNS52807.2021.9441576.

[22] I. V. Ostroumov, N. S. Kuzmenko, K. Marais, Optimal pair of navigational aids selection, in: 2018 IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC), 2018, pp. 32–35. doi:10.1109/MSNMC.2018.8576293.

[23] W. Wang, M. Liu, Hyperbolic spatial covariance modeling with adaptive signal filtering for robust wi-fi indoor positioning, Sensors 25 (2025) 4125.

[24] A. Erofeev, A. Astafiev, L. Karpycheva, O. Astafieva, High-accuracy indoor positioning using wi-fi channel state information and deep neural networks, in: 2025 International Russian Automation Conference (RusAutoCon), IEEE, 2025, pp. 943–947.

[25] O. Bazaluk, O. Anisimov, P. Saik, V. Lozynskyi, O. Akimov, L. Hrytsenko, Determining the safe distance for mining equipment operation when forming an internal dump in a deep open pit, Sustainability 15 (2023) 5912.

[26] W. Lee, P. Geneva, C. Chen, G. Huang, Mins: Efficient and robust multisensor-aided inertial navigation system, Journal of Field Robotics 42 (2025) 3252–3284.

[27] L. Cheng, Z. Fu, An adaptive kalman filter loosely coupled indoor fusion positioning system based on inertial navigation system and ultra-wide band, Measurement 244 (2025) 116412.

[28] Y. Wang, J. Fu, Y. Cao, A weighted hybrid indoor positioning method based on path loss exponent estimation, Ad Hoc Networks 166 (2025) 103684.

[29] I. Ostroumov, N. Kuzmenko, M. Zaliskyi, Global assessment of radio navigation aid networks and their contribution to performance-based navigation implementation, Eng 6 (2025). URL: https://www.mdpi.com/2673-4117/6/12/360. doi:10.3390/eng6120360.

[30] Y. Li, J. An, N. He, Y. Li, Z. Han, Z. Chen, Y. Qu, A review of simultaneous localization and mapping algorithms based on lidar, World Electric Vehicle Journal 16 (2025) 56.

[31] Z. Fan, L. Zhang, X. Wang, Y. Shen, F. Deng, Lidar, imu, and camera fusion for simultaneous localization and mapping: a systematic review, Artificial Intelligence Review 58 (2025) 1–59.

[32] I. V. Ostroumov, N. S. Kuzmenko, Accuracy estimation of alternative positioning in navigation, in: 2016 4th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC), 2016, pp. 291–294. doi:10.1109/MSNMC.2016.7783164.

[33] H. Mosa, A. Saleh, A. Al-Badarneh, Performance comparison of spatial data indexing using distributed systems, in: 2025 International Conference on New Trends in Computing Sciences (ICTCS), IEEE, 2025, pp. 327–333.

[34] DataBase, Flightaware. oficial web, 2025. Https://www.flightaware.com.