

A SOLUTION TO IMPROVE LOCATION DATA ACCURACY FOR MAP-UPDATING FROM MOBILE DEVICES USING THE KALMAN FILTER

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Abstract

With the increasing prevalence of mobile devices, it is possible to continuously collect geospatial data directly in the field such as image data and coordinates of objects. However, location data collected from mobile devices often contains noise and large errors, thus direct integration into spatial database poses challenges in terms of accuracy. In the context of the continuous expansion and infrastructure changes of industrial parks in Vietnam, the application of GPS-integrated GIS technology enables automatic and accurate updates of internal road maps within the parks. This article proposes a framework for optimizing point-based data used to update digital maps from mobile devices. The article uses the Kalman filter as a solution to improve the location data accuracy when updating maps from mobile devices. Experimental programming of mobile devices utilizes the Flutter and MapLibre GL libraries, while the desktop program employs QGIS software. The database management systems used are PostgreSQL and PostGIS/GeoServer. Experiments on updating data on real mobile devices demonstrate that the proposed method can effectively limit location errors and minimize the risks associated with anomalous data. By applying the proposed method, the positioning error has been reduced from approximately 8.23 meters to only 3.11 meters. The experimental results also show significant improvements in coordinates accuracy, data deduplication, and map-updating efficiency.

***Keywords:** Data updating; mobile devices; digital map; Kalman filter.*

1. Introduction

The rapid proliferation of mobile devices equipped with Global Navigation Satellite System (GNSS) receivers and high-resolution cameras has created unprecedented opportunities for real-time collection of spatial data [1]. Such devices enable users to capture both geospatial coordinates and photographic evidence of the

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environment, which can serve as critical sources for updating and enriching digital maps. Digital maps, as the backbone of navigation services, intelligent transportation systems, and location-based applications, require timely and accurate updates to maintain their reliability [2]. However, mobile-derived data is inherently noisy: positional measurements from GNSS are prone to errors caused by multipath effects, atmospheric disturbances, or urban canyon environments, while image data often suffers from inconsistent quality, varying perspectives, and incomplete metadata. These challenges underscore the need for an optimized framework to integrate heterogeneous mobile data into digital maps effectively [3].

In practical contexts, the demand for accurate and up-to-date digital maps is evident across diverse domains. For example, in urban mobility, ride-hailing services and public transportation applications depend on precise road geometry and real-time updates of road closures, construction zones, or traffic diversions [4]. In disaster management, first responders require situational awareness supported by accurate positioning and imagery contributed by mobile users in affected areas, enabling rapid assessment of damage and accessibility. Similarly, in logistics and delivery services, frequent map updates are crucial for optimizing routing and minimizing operational costs [5]. Even in rural development and agriculture, where satellite imagery may be outdated or obstructed by clouds, mobile crowdsourced imagery and location data offer a flexible solution for capturing ground-level changes. These scenarios underline the importance of harnessing mobile devices not only as consumers of digital maps but also as active contributors to their continuous evolution [6].

Conventional approaches to map updating rely heavily on survey data, satellite imagery, or crowdsourced geographic information platforms such as OpenStreetMap [7]. While these methods contribute significantly to digital map maintenance, they either lack real-time responsiveness or face difficulties in ensuring accuracy at fine scales [8]. The increasing ubiquity of smartphones provides an alternative channel for collecting on-the-ground observations, yet translating this raw data into consistent and precise map updates remains a complex task [9]. The primary difficulties include: (i) mitigating positional errors from mobile sensors, (ii) validating and aligning images with existing map features, and (iii) optimizing data transmission and storage to handle large volumes of user-contributed content.

To address these challenges, the article proposes an optimization framework for updating data for digital maps using the mobile, with a focus on two key data sources: coordinates and images collected from mobile devices. The proposed method utilizes Kalman filtering techniques to enhance the accuracy of mobile location data, thereby

improving the precision of locations acquired from mobile devices. Furthermore, data optimization strategies are incorporated to ensure efficient data handling, reduce redundancy, and improve the reliability of updates integrated into the digital map.

The contributions of this article include:

- Propose a solution to update map data from mobile devices.
- Apply Kalman filtering techniques to minimize positional errors.
- Improve both the accuracy and the efficiency of digital map-updating processes through experiments.

The article is organized into five sections: Section 1 introduces the research content; Section 2 presents materials and methodology; Section 3 is results and discussion; and Section 4 is conclusion.

2. Materials and methodology

2.1. Materials

The primary data sources in this study consist of geospatial coordinates and imagery captured by mobile devices (smartphones and tablets). Mobile devices are equipped with GNSS receivers, cameras, inertial sensors (accelerometer, gyroscope), and wireless modules (Wi-Fi, Bluetooth), providing heterogeneous data streams. Two key data modalities were utilized:

- *Geospatial coordinates*: Latitude, longitude, timestamp, and optional altitude values recorded by device positioning systems. These data are prone to errors due to multipath effects, atmospheric conditions, and device hardware limitations.

- *Mobile imagery*: Photographs captured by mobile cameras containing geotagged metadata. Images may include contextual information such as road signs, traffic conditions, construction zones, or new points of interest which are relevant for map-updating.

An existing digital map database, containing road networks, landmarks, and geographic features, is used as the reference framework for integrating mobile-derived updates. The baseline map is assumed to be structured in standard formats such as OpenStreetMap (OSM), Shapefile, or GeoJSON, enabling the interoperability with Geographic Information System (GIS) and navigation platforms.

2.2. Methodology

2.2.1. Programming environment

To implement the proposed optimization framework, we developed two open-source applications: a mobile GIS application (mobile client) for data collection and

visualization, and a desktop client for verification and editing.

- The mobile GIS application uses the Flutter and MapLibre GL libraries to collect and display map data.

- The desktop client uses QGIS software and the PostgreSQL, PostGIS/GeoServer database management systems, allowing to display, check, and manage data.

For the mobile GIS application, we adopted Flutter as the cross-platform development framework to ensure the compatibility with both Android and iOS devices. The application integrates MapLibre GL for interactive map rendering, the geolocator library for GNSS-based positioning, and the camera/imagepicker packages for capturing geotagged photographs. Data collected by the mobile client is transmitted via REST APIs to the backend for processing and optimizing. The mobile GIS application also enables real-time visualization of map updates by consuming map services published through GeoServer.

For the desktop application, we employed QGIS, a widely recognized open-source GIS platform, which connects directly to the PostGIS spatial database and to map services hosted on GeoServer. QGIS provides a user-friendly interface for domain experts to review, validate, and edit incoming spatial updates from mobile devices. Plugins such as the QGIS Processing Toolbox and OpenLayers Plugin further extend their capabilities for the spatial analysis and visualization of background layers from open data sources.

2.2.2. Methodology

When location data is collected from mobile devices, its nature is often erroneous and unstable due to the influence of many factors such as Global Positioning System (GPS) accuracy, sensor quality, environmental conditions (high-rise buildings, forests, weather), or user behaviors (abnormal movement, signal interruption). If this "raw" data is directly put into the digital map database without optimization, many problems will arise:

- Accumulation of noise and errors: Off-set positioning points can create inaccurate locations, distorting the map.

- Increasing storage capacity: Raw data is often repetitive, containing many unnecessary redundant points, causing increased storage capacity, higher processing and query costs.

- Reducing query and analysis efficiency: Databases with too much junk data will slow down the speed of searching and analyzing, and at the same time, it is difficult to ensure the integrity.

- Impact on service quality: Mapping, navigation, or traffic analysis applications based on poor quality data will produce incorrect results, reducing the reliability for users.

Therefore, optimizing location data before updating is a necessary step to filter out noise and anomalies to increase accuracy, eliminate redundant data, standardize data to synchronize with the database structure and easily integrate with other data sources, and increase processing performance when exploiting data in GIS and digital map applications [10].

When using GPS on mobile phones, the data obtained often suffers from random noise ($\pm 5-10$ m fluctuation around the true position), short-term errors due to signal loss or reflection, and time lag when the user moves quickly. To overcome these problems, the article proposes the use of a Kalman filter to smooth the trajectory, re-estimate the true position, and reduce positioning errors by combining multiple measurements over time [11]. Kalman filter acts as a smart combination of measurement data (GPS), low precision but reflecting reality, motion model – predicting position based on direction and velocity [12].

At each time, the algorithm performs two steps:

(a) Prediction step: Predicts the current position based on the previous position and velocity:

$$\begin{aligned} x_{pred} &= x_{prev} + v_{prev} \Delta t \\ P_{pred} &= P_{prev} + Q \end{aligned} \tag{1}$$

The above formula gives the Kalman filter model under the constant velocity assumption where x_{pred} is the predicted position at the current time (estimated before new measurements), v_{prev} is the estimated velocity from the previous step, Δt is the time between two measurements and Q is the process noise covariance (model variation), reflects the uncertainty of the motion model. P_{pred} is the error covariance matrix of the prediction estimate.

Since there are no new GPS measurements in this step, we only propagate the state and update the uncertainty according to the kinematic model.

(b) Update step: When receiving new GPS data (z), the Kalman filter calculates the relative confidence between the prediction and the GPS data:

$$\begin{aligned} K &= \frac{P_{pred}}{P_{pred} + R} \\ x_{new} &= x_{pred} + K(z - x_{pred}) \\ P_{new} &= (1 - K)P_{pred} \end{aligned} \tag{2}$$

where R is the noise of GPS (the greater the noise, the lower the reliability). In the Kalman Filter, R is the measurement noise covariance matrix. R describes the uncertainty or noise level of the measurement sensor, specifically the GPS signal. K is the Kalman coefficient, which determines the reliability level between the model and the measured data.

The algorithm can be written in pseudocode as follows:

Input: *RawDataStream* $D = \{\text{location, timestamp}\}$

Output: *OptimizedData* U sent to *DigitalMapServer*

Step 1: Data Acquisition

For each incoming data point d in D :

if $\text{GPS_signal}(d)$ is valid AND $\text{timestamp}(d)$ is consistent:

Append d to *CandidateData*

else:

Discard d

Step 2: Preprocessing and Noise Filtering

For each trajectory T in *CandidateData*:

Apply $\text{KalmanFilter}(T)$ to smooth noise

Store as *PreprocessedData*

Step 3: Quality Assessment

For each record r in *CompressedData*:

$\text{score} = \text{EvaluateQuality}(r)$ // based on device accuracy, and history

if $\text{score} < \text{Threshold}$:

Discard r

else:

Append r to *QualifiedData*

Step 4: Synchronization and Conflict Resolution

For each record r in *QualifiedData*:

if r already exists in *PendingUpdates*:

$\text{MergeUpdates}(r, \text{PendingUpdates})$

else:

Append r to *PendingUpdates*

Step 5: Transmission

Package *PendingUpdates* into *UpdatePacket*

Send *UpdatePacket* via MQTT/HTTP to *DigitalMapServer*

Step 6: Server Integration

On server:

Validate(UpdatePacket)

Apply IncrementalUpdate(UpdatePacket) to DigitalMapDB

Notify client of update status

End Algorithm

We prioritized open-source solutions because of their flexibility, adaptability, and possibility to customize them according to specific requirements. Open-source software offers the advantage of direct access to the source code and a wide range of libraries, which makes it easier to develop tailored solutions that fit particular needs.

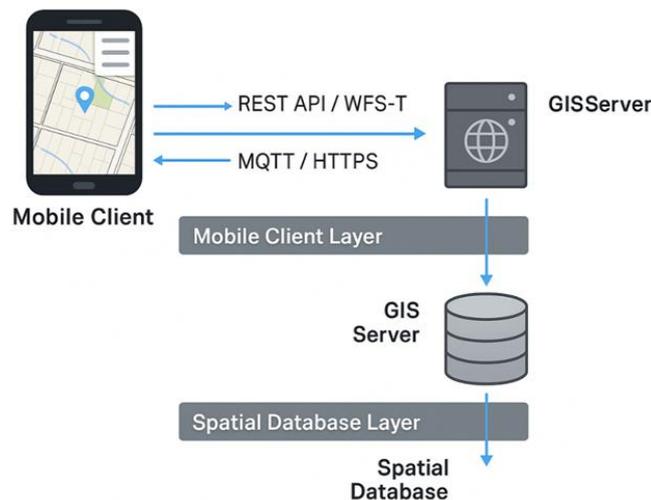


Fig. 1. Mobile GIS architecture diagram for updating map data.

Figure 1 shows the Mobile GIS architecture diagram for updating map data. Main components include: Mobile client, GIS Server, Spatial database:

- Mobile Client: Smartphone, tablet, or handheld GPS device with Mobile GIS application installed. Collect field data (coordinates, photos, videos, notes). Display base map and data layers (basemap, thematic layers). Allow editing, labeling, verifying the information on the spot. Transmit data to the server via network (Wi-Fi, 4G/5G).

- GIS Server: Acts as an intermediary between mobile users and the map database. Receives and checks data sent from mobile devices. Optimizes location data (filtering noise, correcting coordinates errors). Updates map data layers in the central system. Provides map display services, spatial queries.

- Spatial database: Uses PostgreSQL/PostGIS library to store and manage map data (points, lines, areas, rasters, metadata). Data updates, versioning and access control.

The data is stored in a PostgreSQL/PostGIS spatial database. Managers can then connect to the same database from their desktops using QGIS, enabling them to view updates in real time. For sharing road information with end users, QGIS Cloud is used to quickly publish maps created or edited in QGIS. Any local changes applied in QGIS are immediately reflected online, allowing road users to access the most up-to-date road information via QGIS Cloud Map Mobile.

3. Result and discussion

This study examines the effectiveness of applying the Kalman filter to improve the positional accuracy of GPS data collected through a Mobile GIS application for field-based map updates (Fig. 2). The experiment was conducted in Yen Phong Industrial Park, Bac Ninh, Vietnam, covering about 1.2 square kilometers. GPS data was collected using Android smartphones equipped with GNSS sensors at a frequency of one point per second, recording latitude, longitude, timestamp, and metadata such as road name and surface type. Reference data was collected using a dual-frequency GNSS receiver (Trimble Catalyst) as ground truth.

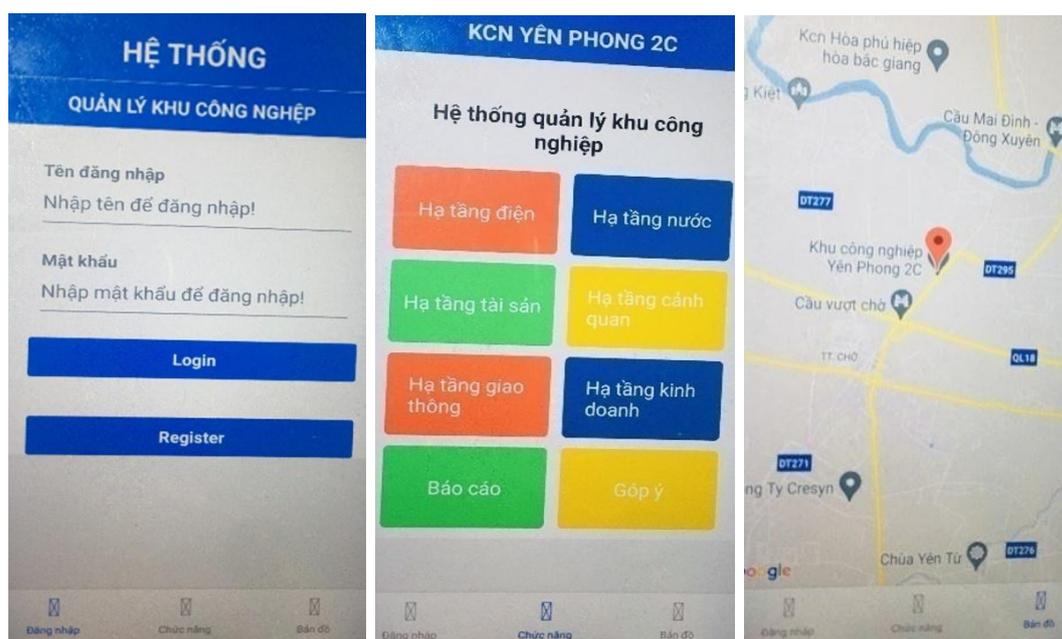


Fig. 2. Some experimental images of building applications on mobile devices.

The Mobile GIS client, using Flutter and MapLibre SDK, transmitted filtered coordinates via HTTPS REST API to a GeoServer-PostGIS system for map updating. The filtering module implements a standard Kalman filter where each GPS observation was treated as a measurement vector, and the state vector represents the position and velocity of the moving user. The filter predicts the next state based on the previous one

and corrects it using new GPS observations according to the Kalman gain, which balances the process noise and the measurement noise. In this configuration, the process noise (Q_k) was set to 0.001, and the measurement noise (R_k) to 5, corresponding to an average GPS accuracy of approximately five meters.

In Tab. 1, experimental results show that the mean positional error decreased from 8.23 m for raw GPS data to 3.11 m after filtering, while the maximum deviation reduced from 15.18 m to 6.42 m and the standard deviation from 4.65 m to 2.21 m. The filtered trajectory closely matched the true road centerline obtained from a reference GNSS device, demonstrating a 50% reduction in spatial variance. Visual comparison between the raw and filtered paths reveals that the Kalman filter successfully smoothed out noise and eliminated sudden jumps, resulting in a continuous and realistic trajectory suitable for integration into the digital map database. The computation time remains acceptable about two milliseconds per point, confirming that the method can be effectively implemented in real-time on common smartphones.

Tab.1. Original data information and data after using Kalman filter

No.	Name	Raw GPS data	Kalman filtered data
1	Maximum deviation (m)	4.65	2.21
2	Standard deviation (m)	15.18	6.42
3	Mean positional error (m)	8.23	3.11

These findings suggest that integrating Kalman-based filtering into Mobile GIS significantly improves the reliability of spatial data and supports accurate, near real-time map updates in field environments.

4. Conclusion

The research results show that the proposed solution can help improve the accuracy and efficiency of digital map updates. The integration of live data from the field with attribute information and coordinates of geographic objects is done conveniently, while significantly reducing errors and abnormal data compared to traditional methods. The article uses Kalman filter to improve the location data accuracy when updating maps from mobile devices. Experiments with mobile devices, Flutter and MapLibre GL libraries, QGIS workstation systems and PostgreSQL/PostGIS/GeoServer databases have demonstrated the applicability of the model in practice. Not only does it improve the reliability of spatial data, but it also significantly improves the timeliness and efficiency of map updates, thereby opening up the development directions for dynamic map systems and GIS applications on mobile platforms.

In the future, expanding the research towards integrating more machine learning algorithms, as well as testing on various types of data and environmental conditions, will contribute to perfecting the solution framework for an accurate, intelligent and flexible digital map update system.

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GIẢI PHÁP CẢI TIẾN ĐỘ CHÍNH XÁC DỮ LIỆU VỊ TRÍ KHI CẬP NHẬT BẢN ĐỒ TỪ THIẾT BỊ DI ĐỘNG SỬ DỤNG BỘ LỌC KALMAN

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Tóm tắt: Với sự phổ biến ngày càng tăng của các thiết bị di động, việc thu thập liên tục dữ liệu không gian địa lý trực tiếp ngoài thực địa, chẳng hạn như dữ liệu hình ảnh và tọa độ của các đối tượng, đã trở nên khả thi. Tuy nhiên, dữ liệu vị trí thu thập từ các thiết bị di động thường chứa nhiều và sai số lớn, do đó việc tích hợp trực tiếp vào cơ sở dữ liệu gặp nhiều thách thức về độ chính xác. Trong bối cảnh các khu công nghiệp ở Việt Nam liên tục mở rộng và thay đổi hạ tầng giao thông, việc ứng dụng công nghệ GPS tích hợp GIS cho phép tự động cập nhật bản đồ đường giao thông nội khu một cách chính xác và hiệu quả hơn. Bài báo đề xuất phương pháp tối ưu hóa dữ liệu dạng điểm được sử dụng để cập nhật bản đồ số từ thiết bị di động. Trong đó, bộ lọc Kalman được sử dụng như một giải pháp cải thiện độ chính xác của dữ liệu vị trí khi cập nhật bản đồ từ thiết bị di động. Việc lập trình thử nghiệm trên thiết bị di động sử dụng các thư viện Flutter và MapLibre GL, trong khi chương trình máy tính để bàn được phát triển dựa trên phần mềm QGIS. Hệ quản trị cơ sở dữ liệu được sử dụng là PostgreSQL và PostGIS/GeoServer. Các thí nghiệm cập nhật dữ liệu trên thiết bị di động thực tế cho thấy phương pháp đề xuất có thể hiệu quả trong việc hạn chế sai số vị trí và giảm thiểu rủi ro do dữ liệu bất thường gây ra. Bằng cách ứng dụng phương pháp đề xuất, sai số định vị đã giảm từ khoảng 8,23 m xuống chỉ còn 3,11 m. Kết quả thực nghiệm cũng cho thấy những cải thiện đáng kể về độ chính xác tọa độ, loại bỏ dữ liệu trùng lặp và nâng cao hiệu quả cập nhật bản đồ.

Từ khóa: Cập nhật dữ liệu; thiết bị di động; bản đồ số; bộ lọc Kalman.

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