

System for Real Time Storage, Retrieval and Visualization of GPS Tracks

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Abstract— Smartphones give users a possibility to georeference photos, follow their sport achievements and share them to peers. We describe a complete real-time system for storage, querying, retrieval and visualization of GPS tracks.

I. INTRODUCTION AND MOTIVATION

Advances in mobile phone technologies and increasing availability of mobile devices with GPS receiver make it possible to record and share a variety of location-based data such as photos, videos or GPS trajectories (tracks). Smartphones give users the possibility to georeference photos, follow their sport achievements (for example distance and speed of jogging) and share their travels to peers [6] without having to use specialized devices. Location-based mobile applications usually record more data than needed to use in the above mentioned scenarios. Big amount of data coming from GPS is not only difficult to store [5], but is also complicated to process, analyze and display to users in real-time.

Therefore, storage, querying, retrieval and visualization of location-based data (GPS tracks and georeferenced multimedia files) are the main issues and operations that must be considered when designing a location-based application, regardless of its purpose, which can be, for example, tourist information [2], ride sharing, location-based collaboration, discovery of interesting trails, urban sensing, health monitoring [3] or recommending interesting places [11].

We present a simple yet efficient system to handle these tasks. The system allows users to record their GPS trajectories and automatic storage of the data online. We use the basic point data not only to visualize tracks on screen, but also for different kind of track analysis tools, such as segmentation, classification [13] and similarity tools. The data analysis is used for giving recommendations in such system as described in [12] and [11]. Tracks recorded by mobile application are displayed in web browser in real time using Google Maps technology. The whole system is embedded in MOPSI project.

The main problems faced are how to store the data, how to present the data to the user and on what devices to present the data. The visualization can be done on a mobile device such as described in [7] or [10], on a separate application

[2], [9] or using a web interface [1], [3], [14].

Other systems have addressed the issues of storage, querying, retrieval and visualization of location-based data, such as GeoLife [14], the system presented in [1] and StarTrack [3].

GeoLife [14] is a project which focuses on visualization, organization, fast retrieval and understanding of GPS track logs. The main contributions of the project consist of visualizing GPS data over digital maps, indexing the GPS trajectories based on uploading behavior of users, search of tracks using spatial range and time query and understand people lives based on raw GPS data. Similarly to our system, user can voluntarily upload their GPS tracks and associated multimedia data and tracks and multimedia are used afterwards for recommendation via web or mobile user interface. Whilst the purpose and functionality of GeoLife and our system are similar, we provide some extra features such as track novelty and similarity and we use different algorithm for travel mode detection.

The tool described in [1] is used for manipulating, integrating and displaying geographical referenced information. The main purposes for the tool are path planning and navigation of mobile objects. The tool can be used in several applications such as: tracking, fleet management, security management and industrial robot navigation. It uses, same as our system, Google Maps to display tracks acquired from GPS receivers and sent through GPRS/3G (mobile) network, although we also display photo collections and live users location. Similarly to our system, a spatial database is used for storing tracks and points. The application proposes a general approach is handling GPS data and it can be used in a variety of applications that use track recording, navigation and track planning. It requires that the user selects the points and defines the tracks, but, in turn, our application automatically detects and segments the tracks.

StarTrack [3] and its improved version in [8] describe tracks of location coordinates as high-level abstraction for various types of location-based applications. The system supports the following operations: recording, comparing, clustering and querying tracks. Track similarity algorithm is similar the algorithm we apply and track clustering uses k-medians algorithm proving that is more convenient method than k-means. Experimental results show that the system is efficient and scalable up to 10.000 tracks. The improved version was extended so it can operate on collections of tracks, delay query executions and permits caching of query results. Other improvements are canonicalization based on

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road networks, and using track trees for computing similarity.

II. SYSTEM DESCRIPTION

The architecture of the implemented system is illustrated in Fig. 1. Any GPS enabled smartphone can be used to record position data of its user. The data sent by mobile device are saved in database. The saved data are then accessed and processed to input format required by geographic information system. This system is responsible for data visualization and it is implemented in web browser with use of embedded map.

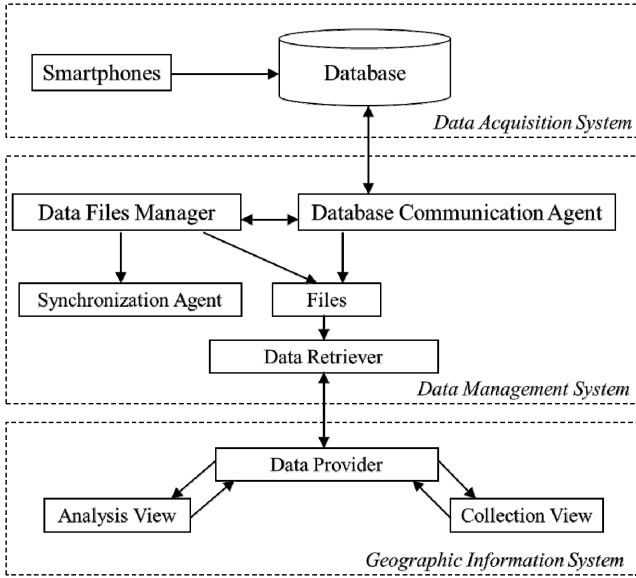


Figure 1. System diagram.

A. Data acquisition system (DAS)

Data is collected using GPS enabled smartphones (data collection screen on Symbian device is presented in Fig. 2). We developed data collection applications for operating systems such as Symbian, Android, iOS and Windows Phone operating systems. The application records user's location (latitude and longitude) and time as UNIX timestamp. Such triple is saved in time interval of 1 to 4 seconds (2 by default) depending on user settings. The data is buffered on the device and sent every 30 seconds to server over the Internet. In case of the Internet network connection malfunction, the application retries to send data later when connection is operational again. The database management system used to store data is MySQL. It was selected as it is reliable open source software and it was used already in similar projects [1]. The data table structure used for saving incoming GPS data is presented in Table I.

TABLE I. STRUCTURE OF GPS DATA TABLE.

Field	Type
id	int
userId	int
point	Point
timestamp	int



Figure 2. Data collection screen on mobile device.

B. Data management system (DMS)

The data management system links database, where all data from mobile device is stored, with the geographic information system, which displays the data to the user. This component of the system retrieves required data from database and provides it to visualization system as shown in Fig. 1.

In current version, this task is carried by PHP scripts and Java applications and uses a synchronization agent (implemented as cron job on server) for scheduling the execution of the Java application. Due to large amount of data, the data management system architecture was modified when querying the database and processing the query results was not done in real time anymore. In the previous version of the system everything was carried by PHP scripts, but we incorporated the Java application to speed up process (experiments in section IV show time difference between these 2 solutions). Moreover, the current system supports more tasks. It prepares data not only for displaying tracks collection and analyzing single track, but allows calculating and displaying track similarities.

The data management system retrieves requests for data from geographic information system, which specifies the user and the time range of the tracks. The PHP scripts check then availability of track data in preprocessed files. If not all tracks are found there, they are retrieved directly from the database, as a collection of points. However, in practice, the database is queried only in case of new tracks (in the worst case tracks uploaded 24 hours prior to the request), thus it is fast to retrieve the track data and provide it to the visualization system. The output of the script is a file with list of tracks uploaded by specified user in given time interval. The Java application is started and run every 24 hour by a cron job. The application saves tracks from database as text files and each file is uniquely identified by user identifier and track timestamp. Such text file contains

each point of the track characterized by latitude, longitude and timestamp in separated line.

Further processing is required in case of displaying track collection when the visualization system needs to handle large number of points. We use track reduction algorithm written in C to reduce number of points to be displayed. Detailed description of the algorithm and its benefits is given in [5]. Other solutions such as [4] choose to run track reduction algorithm directly in mobile devices in order to save energy and minimize the amount of data transfer, however, we choose to collect all raw GPS data from mobile devices and process it server-side because we need an accurate dataset for data mining.

C. Geographic information system (GIS)

GIS is a method that manipulates, analyzes and presents geographical data. Our GIS is developed based on Google Maps API similarly as the one described in [1], although we offer support of using extra layers such as OpenStreetMap¹. We decided to embed Google Maps in our system as they are freely available and accessible over the Internet and provides map, satellite and hybrid view for convenient browsing of data by users. We offer also OpenStreetMap data as a layer over Google Maps because it allows users to get more accurate maps in some areas. The GIS uses several layers to provide different type of geographical information. Google Maps API allows embedding of several of such layers. The layers of our system are listed below and presented graphically on Fig. 3:

- 1) GMarker – to show location of start and end points of tracks, to animate movement of user along track
- 2) GPolyline – to display whole track as a line of points recorded by mobile application
- 3) GInfoWindow – to present information about tracks such as track duration, length and average speed

As described above, our GIS queries data management system based on user identifier and time. We present track data in 2 different views: collection and analysis view.

User collection view displays whole user track collection in given time interval as shown in Fig. 4. Geographical data is visualized on map using the layers listed above. Hence, the map displays not only points of tracks, but also shows statistics such as duration of track, its length, average speed and start and end point. The latter two are presented as GMarkers on map based on actual coordinates and as street address in GInfoWindow. For convenient browsing of track collection, track list sorted by time is displayed next to map.

From the track collection view user can switch to the analysis view. The view allows analysis of the track by finding segments and transportation mode used as described in [13] and presented on Fig. 5, as well as similar tracks (Fig. 7). Fig. 6 shows track animation tool which is part of the analysis view and visualizes user movement with respect to transportation mode, speed and time.

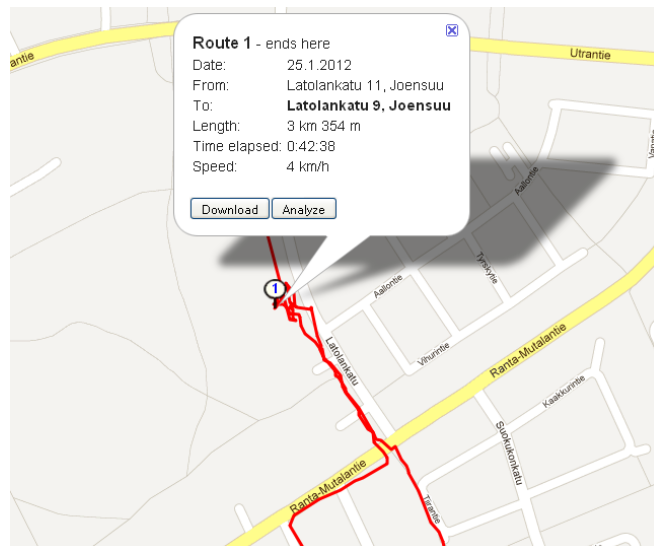


Figure 3. Layers of Google Maps embedded in the system.

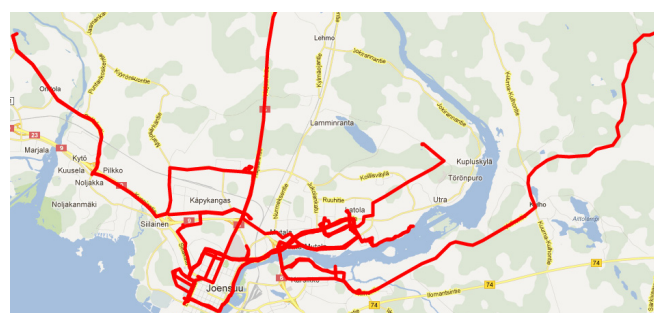


Figure 4. Track collection in selected time period.

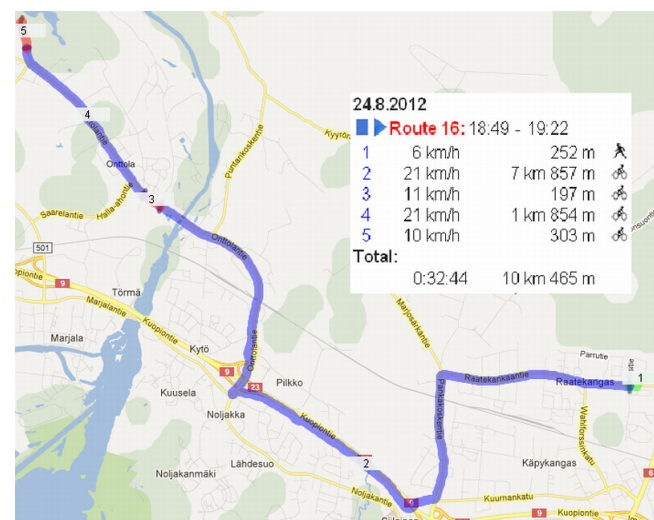


Figure 5. Analysis view (segmentation and classification statistics).

¹ <http://www.openstreetmap.org>

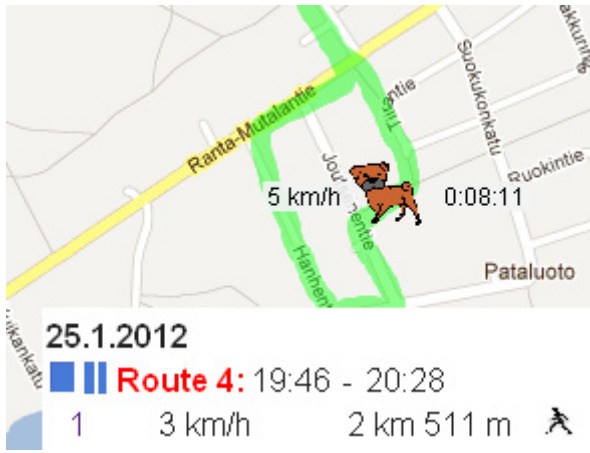


Figure 6. Analysis view: animation of walking track.

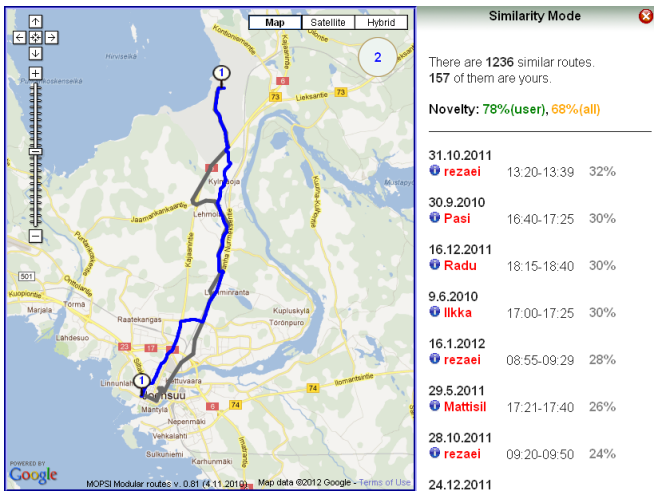


Figure 7. Analysis view: similarity search screen.

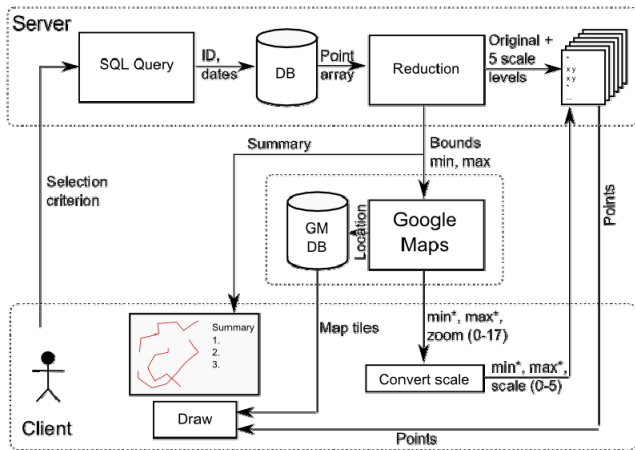


Figure 8. Typical workflow of the proposed system.

III. RESULTS

The developed system was tested with a set of tracks recorded during over 3 years by around 10 constantly active users and over 100 less active users. Collected tracks consist of over four million points.

Track reduction algorithm decreases number of points

needed to represent track on map [5]. Thus rendering time is significantly reduced at this stage.

Furthermore, querying database directly is slower than using proposed file based system. It is caused by various reasons. Firstly, database contains large amount of data stored in basic structure as points not related to each other. Secondly, data in our system are often queried by time not by geographical boundaries thus we do not benefit from spatial queries much. Thirdly, we greatly reduce number of queries to database required by some of the tasks performed by the system. For instance, track similarity compares each track with every other track in the system, but we query database only once to retrieve all the tracks and at the same time we do not store the tracks in track similarity program memory.

In order to evaluate performance of the data management system we measure time needed for data processing by data management system and time for displaying information to user in web interface. The measurements are performed on typical workflow of the DMS and GIS presented on Fig. 8. Additionally, we compare performance of our current system with the old one. Results are presented in Table II.

TABLE II. COMPARISON OF EXECUTION TIME (MILLISECONDS) OF DATA MANAGEMENT SYSTEMS (DMS) AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) WHEN QUERYING TRACK COLLECTION BY TIME.

period	tracks	points	previous system		current system	
			DMS	GIS	DMS	GIS
User 1						
all	641	928439	163318	3597	15993	3757
last year	224	446779	82744	786	12148	1005
last month	20	37686	6971	190	2053	214
last week	6	9755	1406	140	1150	213
most recent	1	1499	220	163	1166	163
User 2						
all	478	704146	125455	2439	11335	2144
last year	221	377048	65455	681	7610	769
last month	22	56942	6047	173	2226	186
last week	5	21733	2437	153	1583	201
most recent	1	4049	366	176	1176	182

The average percentage of time needed to process steps shown in Fig. 8 (querying, reduction, visualization) is visualized in Fig. 9.

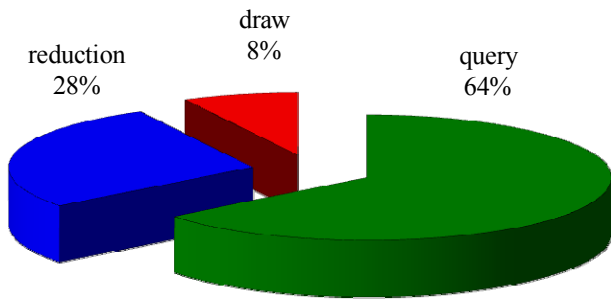


Figure 9. Percentage of time used for querying, reduction and drawing.

IV. SUMMARY

The presented system possess a capability of acquiring raw GPS data from mobile device and extract from it for example position, time and speed that can be preented in real time by GIS module. All incoming data is saved continuously by DAS module. The GIS module has implemented several ways of presenting tracks collected. Its functions include browsing track collection by time, viewing time, speed, position and altitude of each point, track segmentation and classification, finding similarities between tracks and visualization of object movement by animation.

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