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Understanding tourist behavior using large-scale mobile sensing approach: A case study of mobile phone users in Japan

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ABSTRACT

This article describes a framework that capitalizes on the large-scale opportunistic mobile sensing approach for tourist behavior analysis. The article describes the use of massive mobile phone GPS location records to study tourist travel behavior, in particular, number of trips made, time spent at destinations, and mode of transportation used. Moreover, this study examined the relationship between personal mobility and tourist travel behavior and offered a number of interesting insights that are useful for tourism, such as tourist flows, top tourist destinations or origins, top destination types, top modes of transportation in terms of time spent and distance traveled, and how personal mobility information can be used to estimate the likelihood in tourist travel behavior, i.e., number of trips, time spent at destinations, and trip distance. Furthermore, the article describes an application developed based on the analysis in this study that allows the user to observe touristic, non-touristic, and commuting trips along with home and workplace locations as well as tourist flows, which can be useful for urban planners, transportation management, and tourism authorities.

1. Introduction

With recent advances in information and communications technology (ICT), the cities of today have become increasingly instrumented and interconnected. The activities and movements of urban dwellers are constantly measured and recorded by ubiquitous sensors embedded in urban systems (e.g., CCTV, building access systems, public Wi-Fi) as well as by personal electronic devices (e.g., mobile phones, laptops, tablets). A large number of individual digital traces are generated from which community and city-level behavioral signatures can be captured. Collectively, an image of urbanism of the real (physical) world can be reconstructed digitally. Consequently, an analysis of the characteristics of a city, its functionalities, and the behavior of its inhabitant can be performed, as reported in recent studies. For example, Phithakkitnukoon et al. [1]

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introduced a map that shows most probable activities in different areas of a city from which they found that people who work in the same industry (e.g., restaurant, retail, etc.) tend to have similar daily activity patterns, based on their analysis of connected cell tower locations (Call Detail Records (CDRs)) of nearly one million mobile phone users. Longitudinal mobile phone locations can also help reveal interesting characteristics of human mobility, as indicated by Gonzalez et al. [2], who discovered that despite the diversity of our travel history, human beings follow simple reproducible patterns. Likewise, Song et al. [3] found that people are 93% predictable regarding where they go. Song et al. [4] later developed a model that reflects the tendency of people for commuting between fixed locations on a regular basis. Contributing to these efforts, Phithakkitnukoon et al. [5] showed that people's traveling patterns are influenced by the geography of their social ties.

Human mobility is one of the most important ecological and social challenges of the 21st century. People travel for different purposes, e.g., commuting and tourism. Commuting trips are typically repeated with unchanged routes; hence, such trips are relatively predictable. On the other hand, touristic trips are less predictable. As such, understanding tourist traveling behavior is important for urban planning, transport management, and tourism authorities. Today's pervasive technologies, such as mobile phones that have become an indispensable part of many people's lives, and as seen in recent research studies, with sensing capabilities that help turn the phone into become a personal sensor, collectively create a new sensing paradigm that incorporates humans as part of a sensing infrastructure. By taking advantage of the sensing capabilities of mobile phones, researchers are able to collect an unprecedented amount of fine-grained behavioral data from people. It offers a great advantage over conventional survey studies of tourist behavior.

Traditional tourist behavior studies tend to rely on surveys and questionnaires. For example, Alegre and Pou [6] used survey data gathered from 56,915 tourists over three years to study the length of stay at Balearic Islands in Spain. Gokovali et al. [7] analyzed three-week questionnaire data collected from 1023 tourists to study the length of stay on vacations in Bodrum, Turkey. More recently, Wu et al. [8] studied the choice-making process of Japanese tourists based on survey data collected from 1253 respondents in Japan.

In this work, we used large-scale mobile sensing approach to analyze tourist behavior. We analyzed GPS location traces of 130,861 mobile phone users in Japan collected for one year. The rest of this article will describe our approach in using GPS location records to detect tourists. From these records, we were able to perform tourist behavior analysis and demonstrate applications that can be useful for urban planners, transport management, and tourism authorities.

The main contributions of this work include the following:

- a computational framework for identifying touristic trips from GPS location information (including algorithm for home and work location detection);
- a large-scale (country-level) analysis of tourist behavior, including touristic flows, time spent at destinations, choice of transportation mode, relationship between personal mobility and travel behavior, and similarity in travel behavior;
- a prototype application developed based on the analysis that allows the user to observe and analyze touristic trips and flows.

2. Identifying tourists

2.1. Data

We capitalized on the opportunistic sensing paradigm that mobile phones can be personal sensors to use this personal communication device as a location tracker for our analysis. We used the GPS location records collected for a full calendar year (1 January 2012–31 December 2012) from 130,861 mobile phone users in Japan. The data was provided to us by one of the leading mobile phone operators in Japan, and collected from subscribers who registered for location-based services (and given consent for the use of their location information). The location information was sent through the network and used to perform specific analysis, from which certain services were then provided to the registered users, as shown in Fig. 1(a). To preserve user's privacy, the dataset was completely anonymized by the mobile phone operator before sending it to us. Each entry in the dataset included: unique user ID, position (latitude, longitude), timestamp, altitude, and approximate error (i.e., <100, <200, or <300 m). To reduce battery consumption, an accelerometer was used to detect periods of relative stasis during which power-consuming GPS acquisition functions can be suspended. The sampling rate thus varied with the user's mobility but did not exceed once every five minutes. As an example, Fig. 1(b) shows location traces of a mobile phone user in our dataset.

Some of the subjects from our pool of subjects did not have GPS location traces for the entire year of our study for various reasons, such as the phone being turned off, not being subscribed to a service, or travel abroad; therefore, to ensure sufficient amount of data for our analysis, we selected the 130,861 subjects whose GPS locations were observed at least 350 days out of 365 days in 2012 (95%).

2.2. Home and workplace location detection

In order to identify tourists from GPS trajectories, first we must detect the subjects' home and workplace locations to consider non-commuting trips only. It is from such non-commuting trips that touristic trips can be determined. To detect home and workplace locations, there are three steps in our approach, as depicted in Fig. 2.