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GreenBicylcing: A Smartphone-based Public Bicycle Sharing System for Healthy Life

Yifan Zhao, Longbiao Chen, Chao Teng, Shijian Li, Gang Pan
College of Computer Science
Zhejiang University
Hangzhou, China
{yifan0216, MichZc.Teng}@gmail.com, {longiaochen, shijanli, gpan}@zju.edu.cn

***Abstract*—Gas-consumed urban transportation causes the problems of environment pollution and traffic congestion. Bicycling is an alternative transportation way for short-distance movement, which is a green and healthy style. Some modern cities are building Public Bicycle Sharing System (PBSS), so that inhabitants and tourists can temporarily use bicycles anywhere in the city. In this paper, GreenBicycling, a smartphone-based Public Bicycle Sharing System for healthy life is developed. GreenBicycling aims to improve the user experience and encourage cyclist to use BSS. It allows cyclist to query not only the current information of rental spots, but also the forecast state. To achieve this goal, an improved back propagation network prediction model is proposed. In addition, a quantitative measurement of calorie consumption in a riding trip is introduced into GreenBicycling, so that the cyclist could get intuitive understanding of how much calorie reduction from the riding. A simplified version of the GreenBicycling APP has been released in the Windows Phone Market.**

Keywords—Low-carbon; bicycle sharing; forecast; healthy life

I. INTRODUCTION

The 2012 Global Environment Assessment [1] shows the global energy consumption grows on average at 2% per year, 80% originates fossil fuels. Traditional transportation systems not only consume huge amount of fossil energy, but also lead to serious air pollution, especially due to traffic congestion. For instance, analysis shows the economic loss attributable to traffic congestion in 83 cities in 2000 was approximately $31 billion dollars [7].

On the other hand, many urban commuters who live a fast-paced life can hardly squeeze time to take physical exercises. According to [8], to promote and maintain health, adults are recommended to take a minimum 30 minutes aerobic physical activity 5 days per week. Insufficient physical exercise may reduce personal fitness and lead to potential risk for chronic diseases [8].

Therefore, many city administrators are encouraging its citizens to commute using bicycles to reduce traffic congestion and improve health. In 1965, the first Public Bicycle Sharing Service (PBSS) program was launched at Amsterdam. Since then, hundreds of modern cities have provided PBSS, and many of these services are managed by computer system [9]. For instance, in 2008, Hangzhou started one of the largest PBSS program in the world, the Hangzhou Public Bicycle Sharing System. Currently, there are more than 2300 rental spots distributed across the city, and each spot has 10 to 30 bicycles slots. This system has achieved significant success in reducing traffic congestion and relieving commuting efforts.

Many of these PBSS systems provide web and mobile applications to help user address rental spots, check available bicycles and slots, and even arrange trips. Despite the convenience they brought, these systems face several common challenges in providing comfortable bicycle sharing and riding experiences.

- **Providing context-aware bicycle information.** Though users can query and locate rental spots and bicycles via these systems, the information service is not user-friendly. To find out if a rental spot is full or empty before arriving, the user tends to query the spots via PBSS information service, However, the state of rental spot (full, empty) may change rapidly in a short duration, for instance, the commuting time, holiday, etc. Thus, the current information of rental spot to the user is unreliable. In a similar way, the problem occurs when the cyclist tries to return the bicycle but he can't determine which rental spot to return his bicycle.
- **Promoting healthy lifestyle.** PBSS promotes a green and healthy life style, but there is no quantitative measure of the amount of physical exercise that the user did and the contribution he makes for the environment. Thus, the usefulness of PBSS is hard to evaluate and users do not have incentives to use the system. Most citizens just consider PBSS as a tool of transportation rather than exercise due to the lack of evaluation and activation of the system.

In this paper, a smartphone-based public bicycle sharing system called GreenBicycling is proposed to address the above challenges. GreenBicycling aims to providing context-aware bicycle information and promoting healthy lifestyle for cyclists by leveraging existing PBSS resources. Specifically, GreenBicycling focuses on the following two aspects.

- **Bicycle Number Prediction.** GreenBicycling provides user-friendly interfaces for cyclist to query bicycle number of any rental spots, and forecasts its trends upon arrival. In order to provide reliable prediction results, an improved prediction model is proposed to eliminate the errors generated by bicycles redistribution [16].
- **Calories Measurement.** Cyclists can get quantitative measurement of their calorie expenditure during a

riding trip, thus helping them keep track of their physical exercises. In this paper, we use a simple but economical calorie consumption estimation model based on riding distance and velocity.

The rest of this paper is organized as follows. Chapter 2 reviews the related work about the bicycle sharing system. Chapter 3 introduces GreenBicycling from a brief view of the system architecture. The following chapters tell the detail of implementation of each component and the conclusion.

II. RELATED WORK

By the year 2011, there were about 136 PBSS programs in 165 cities (In China, France, Spain, Germany, UK, Canada, US, Australia, etc.) [9]. The idea of PBSS is that the commuters can take bicycle whenever they want. All the bicycles in the PBSS are customized from the same manufacturer in the same standard to thwart bicycles theft. Some of the PBSS are free, but the citizens have to pay penalty if the bicycle is returned more than an hour later to inhibit malicious occupancy of bicycles.

These PBSS systems have been studied extensively in the recent years. Most studies focus on the deployment and maintenances of the PBSS systems, the distribution density and availability of rental stations, etc. Since the success of the PBSS heavily depends on the network of bike paths and the location of rental spots, Lin and Yang [3][4] focus on the strategic design of the bicycle sharing system and proposed a mathematical model which determines the number and location of bike spots. However, unpredictable problems expose after the rental spots are deployed. For instance, the users always have preference to borrow bicycle from one rental spot and return to another. This leads to an imbalanced distribution that some spots are always full without empty slots to park while others are always empty without available bicycle to borrow. Some works study the repositioning according to the spatial and temporal information of bicycles at the rental spots because of such distribution imbalance [2][3][11]. However, though it will improve the user experience and these researches try to minimize the maintenance cost as much as possible, the service provider still has to spend lots of effort. Thus, Fricker and Gast [10] proposed another solution that offers incentives for users who return bike to least loaded station.

Furthermore, the data produced in the large-scale BBS system is also valuable for data mining. Kaltenbrunner and Rodrigo [16] study the human mobility in PBSS and detect the temporal and geographic patterns of the rental spots. It inspires us to design a predictor in GreenBicycling that implements the prediction feature. In addition, visualization method is proposed to understand cycling behavior via PBSS [12].

As the 3rd generation PBSS achieves great success, the next generation PBSS is conceived as more efficient, sustainable and ease-to-use [13]. These features can be accomplished by the above researches, along with some smart bicycle prototype that can calculate pedal load, share riding experience, path, etc.[14][15].

III. GREENBICYCLING SYSTEM ARCHITECTURE

GreenBicycling is proposed to provide more intelligent features under the existing infrastructure. As shown in Fig. 1, it consists of Smartphone Application Layer and Service Framework Layer. The application layer provides two major features, Intuitive Visualization and Riding Calories Estimation. The system communicates with PBSS which is made up of a set of 'Rental Spot'. We will introduce how they work in the rest of this chapter.

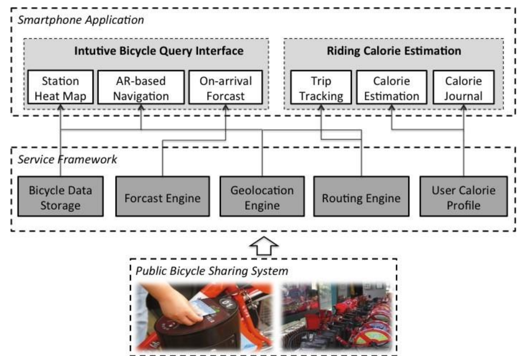


Fig. 1. Architecture of the GreenBicycling

A. Service Framework

1) Bicycle Data Storage: This module peridically pulls data from the rental spot and stores the history data. It publishes the free slots and availiable bicycles of rental spots so that everyone can query them via Internet. On the other hand, it provides temporal sequence to Forcast Engine to predict the future state.

2) Forcast Engine: Forcast Engine gets the current and history data from Bicycle Data Storage and predict the future.

3) User Calorie Profile: This module is inspired by SmartShadow [18] which is a digital shadow to describe a real individual and can be considered as SmartShadow customized for cyclist. The data generated by cyclist such as history trace and calories consumption of riding will be pushed to this module. It is not only cloud backup, but also the cyclist context.

4) Geolocation Engine: This module provides geographic information for the presentation view. Since it's specific for PBSS, it should display the detailed geo information of bicycle rental spots.

5) Routing Engine: Routing Engine will find the shortest path and distance of two specific points. Depending on such feature, the Station Heat Map can rank all the rental spot in descending order of distance and show the nearby spots first. And it can fill sparse sampling GPS points to draw riding trace to calculate cyclist's mileage so that Riding Calorie Estimation module can caluclate calorie consumption.

B. Intuitive Visualization

GreenBicycling utilizes the necessary data from the service framework to present several intuitive views for different user groups.

1) Station Heat Map: This module ultilize Bicycle Data Storage, Geolocation Engine and the Routing Engine. At the presentation layer, it provides both map view which shows rich spatial information and simple view which only shows a text list ranking by distance.

2) AR-based Navigation: Station Heat Map provide a intuitive view to tell the geographic informaion. However, cyclist should have sense of direction to handle such presentation. Therefore, the system makes heavy use of the smartphone sensors to provide an augmented reality view, which shows the rental spot information at the right place in camera view.

3) On-arrival Forecast: AR-based Navigation best ultilizes the spatial information of rental spot and the device sensors. It's the easiest way for user to hunt bicycle nearby. However, the current information of rental spot is far from enough. User will query the GreenBicycling before arriving at the rental spot. It means that the user has to take several minutes to walk to the rental spot while the current information is not reliable as reference of future time. Furthermore, the states of rental spots change rapidly during some specific period, esspecially rush hours in the daytime. Therefore, GreenBicycling make use of the temporal relation history of the rental spot information from Bicycle Data Storage to predict the future time. Combining with Routing Engine module which tells the time cost to arrive at the rental spot, this module can present the future information when cyclist would arrive the rental spot and helps cyclist to make his riding plan.

Based on the work of Kaltenbrunner and Li [16][17], we test Autoregressive Integrated Moving Average model (ARIMA) to predict how many empty slot of the rental spots at future times. ARIMA model is the extension of basic ARMA model, which allows difference before training and prediction to guarantee the stability of time series. The model can precisely forecast the number of free slots in the scope of at least one day in most of cases. However, the efficiency of the algorithm may be quite low because each recalculation requires reloading the data used before and the amount of data is accumulated day by day. What's worse, there are emergencies that the service maintainer will irregularly redistribute the bicycles by carrying them from full rental spot to empty one so that the number of empty slots of rental spot may suddenly change. This case, which is unpredictable in our prediction algorithm, does a lot of harms to our prediction precision. Therefore, we modify and improve a popular model, namely back propagation network (BP network), with gradient descent method to achieve the predictor.

The architecture of a BP network consists of three layers, namely input layer, one or more hidden layers and an output layer. All input nodes are connected to hidden nodes with certain weight *w*, and all hidden nodes are connected to all output nodes with certain weight *v*. There are generally two stages in the training process. First, the neurons in the hidden layer accept the input modified by the weighted connection and then produce stimulation to generate the predicted output. Then the difference between the predicted data and the real data is passed back to modify the weighted connections w and *v*. This network training procedure continues until the total error of prediction in the training set is acceptable or the maximum training time is reached. The BP network is widely used in prediction, such as the prediction of the mechanical properties of porous NiTi shape memory alloy prepared by thermal explosion reaction [5] and the prediction of the processing parameters of liquid extrusion [6].

In detail, we choose

$$y_i = \frac{1}{1+e^{-x_i}}$$

as activation function which is the most commonly used one. And we normalize data by the formula

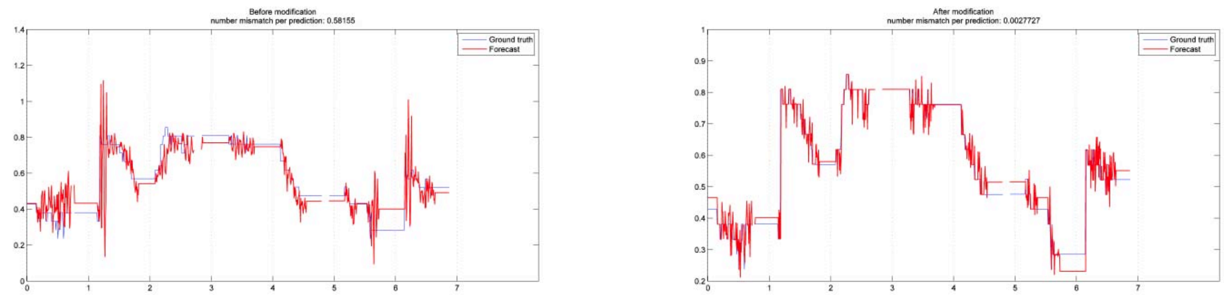
$$y = \frac{x - x_{min} + A}{x_{max} - x_{min} + A}$$

which avoids the appearance of 0 in the process.

In our case, we use the percentage of free slots as input parameter, which offers a more preferable and simple data interface to model. The model itself is quite easy to achieve, while the parameters and modifications are the main difficulties in our cases.

An improvement of our model is to overcome the sudden change in data series caused by the service maintainer. In our previous ARIMA model, it's hard to deal with this issue since the model is periodical and it stabilizes the sudden change in its prediction (which inevitably causes an offset). However, our raw BP network is quite sensitive to the sudden change, so it offers us chance to modify the prediction outcome after prediction. As Fig. 2(a) shows, without modification, the model's prediction result near the catastrophe is quite abnormal. So a sensible idea is to verify whether there is a sudden change in the previous data by comparing the predicted data and the previous data. The threshold is determined based on the statistical information about the historical average change in certain station. The strategy to determine the threshold is to always calculate the average mutation until confronting the abnormal point whose difference with the most recent data is three times than the average mutation. Then the average mutation is reset. This strategy can successfully eliminate the influence caused by the behavior of service provider and precisely calculate the threshold based on the mutation trend of certain station. If the difference between prediction and the most recent data surpasses the threshold, it is thought to be an abnormal change and the solution is to modify this predicted data into the most recent one. The outcome of the modified version is shown in Fig. 2(b). The sudden change in the prediction is removed, while the regular change is still available.

Furthermore, we should take care of the input parameter. Previously there is no theoretical principle or practical attempts to determine the best window size. It's sensible to limit our data scope in one day since everyday pattern is quite different. We test the average error per prediction from 1 hour (6 points) to 24 hours (144 points), which are shown as Fig. 3.



a) Before Error Compensation

b) After Error Compensation

Fig. 2. Accuracy Evaluation of The Prediction Model

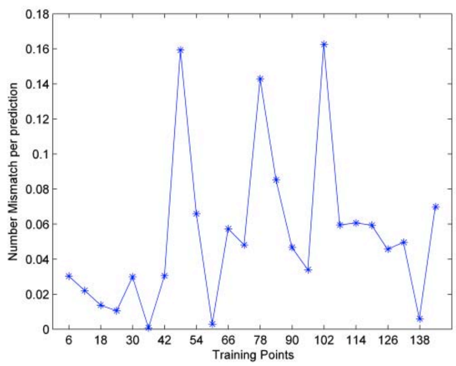


Fig. 3. Determination of Window Size

The error per prediction is quite small and it is quite efficient since there is merely 36 points in every set of input data.

The modified BP network performs quite well in practice. The short-time prediction is acceptable by the users and also, the calculation on the server is efficient. In the future, we will continue developing our model into an online version, which saves a large quantity of storage on the server.

C. Riding Calorie Estimation

1) Trip Tracking: When the user arrives at rental spot, he can open GreenBicycling to start or to end riding travel, and the Riding Calorie Estimation module will take corresponding action, opening or closing the sensors which collect the riding data. Since Near Field Communication (NFC) technology is integrated into the latest smartphone, an auto-trigger that GreenBicycling is automatically waken up or turn off when user arrives at a rental spot and touch the bicycle can be implemented in the future.

2) Calorie Estimation: We introduce a simplify model from HealthStatus which is widely used to estimate calories consumption as the following equation shows.

$$Cal = \eta \times T \times W$$

Where T indicates the number of minutes for activity, W is the weight of user and η is the coefficient depends on activity type as shown in TABLE I. The coefficient shows that in same time duration, higher velocity burns more calories. The GreenBicycling will record the start and end time so that T can be acquired.

TABLE I. ACTIVITY COEFFICIENT

η $(Cal \cdot min^{-1} \cdot lbs^{-1})$	**Cycling**		
	Cycling Leisure	***Cycling 12-14mph***	***Cycling 14-16mph***
	0.03	0.066	0.08

3) Calories Journal: It's a presentation module to show calories consumption in the unit like day, week and month. Since the Calorie Estimation module will backup informationin in the User Calorie Profile, this is considered as eternal storage.

IV. IMPLEMENTATION

Based on the GreenBicycling architecture shown in Fig. 1, we have implemented the system prototype. The application with stable features has been released at Windows Phone Market[1]. In the system, a cyclist is able to estimate the calories consumption based on an economic and classic model. We wrap the official querying Application Programming Interface (API) from PBSS and deploy Bicycle Data Storage, User Calories Profile and Forecast Engine at the server side because of the limited capability of smartphone. On the other hand, we integrate the rest of the Service Framework and Smartphone Application Layer into a smartphone application to simplify the user's operation.

A. Service Framework

1) Bicycle Data Storage and User Calories Profile: Though the Bicycle Data Storage and User Calories Profile both provide storage feature to the application layer, their requirements are different. Bicycle Data Storage just provide snapshots of all rental spots at a certain time to the Forcast module and there is no requirement for complex query. Therefore relational database is not necessary. These snapshot files are just saved on the server in text format with timestamp as file name. User Calories Profile utilizes LAMP (Linux + Apache + PHP + Mysql), a popular open source framework to

1 http://www.windowsphone.com/s?appid=85da4f27-e5d0-4468-baf0-55e8ecb904ed

backup cyclists' riding record in case of unavailability of the smartphone.

2) Forcast Engine: Forcast Engine and the above modules run at a cloud server with Ubuntu 12.04 Operation system. It periodically (10min) pulls raw data from the rental spots for the prediction process to update its algorithm coefficients. The cyclist can get the service from it via HTTP GET method as followed:

$$URL?uid = userid\&geo = lat, lng$$

The $userid$ denotes a unique identification of the user and geo represents the location of the user. Based on these two parameters, Intelligent Cache can calculate the remaining distance and the arriving time of user. According to the time, the prediction process will respond with the reliable information of each rental spot and finally return a JavaScript Object Notation (JSON) format resource, which is a light, standard and understandable Internet format as followed:

```
{"5390":"5,16,7,14,1.12",
 "5391":"18,3,18,3,0.53",
 …
 "5389":"19,2,19,2,0.66"}
```

The number '5390', '5391' represents the identity of the rental spot and the following parameters successively represent the number of current available bikes, current free slots, predicted available bikes, predicted free slots and the distance of station from current location (call the Routing Engine Service).

3) Geolocation Engine and Routing Engine: We adopt Amap as the 3rd party map service since it provides the most detailed geographic information in China. We utilize its routing query feature to build the Routing Engine and its map control to build Geolocation Engine.

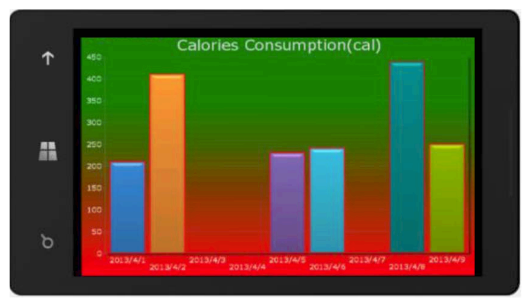
B. Intuitive Visualization

1) Station Heat Map and On-arrival Forcast: The smartphone we use is Nokia Lumia 800 with 1.4GHz CPU, 512MB memory, which carries Windows Phone 7 operating system. Basically, the user can query rental spot via map view which shows the geographic information. We use the MVVM (Model View ViewModel) pattern to design the application since it fits the MS Silverlight technology and it's easy to expand feature and user interface. The application will display 4 views for cyclist, namely 'List View', 'Map View', 'Calories View' and 'AR View' as Fig. 4 (a)(b)(c)(d) show. In these views, each spot on the map provides not only the current information, but also the arriving time of the user. Therefore, new users would find as many helpful information as possible and veteran cyclist can get enough information without redundancy. In the rich view, pie chart is introduced as data visualization to describe rental spots. The radius, sector and blank represent the total parking space, the number of available bicycles and slots. Each spot show not only the current information, but also the predicted time when renter arrives at the spot.

2) AR-based Navigation:

Augmented Reality is a popular technique for wearable device that makes use of camera, gyroscope, GPS, etc. to project virtual object to physical world via camera view. GreenBicycling adopts an open source software GART (Geo Augmented Reality Toolkit) which help people to quickly and easily build AR application for Windows phone. User are allowed to control whether enable AR view in application setting. When it's turned on, GreenBicycling will show map view when the smartphone is horizontally placed and it will automatically switch to AR view when it turns to vertical posture. Fig. 4 (d) shows the AR view, all the rental spot within several hundred meters will be projected into the camera view.

a) Rich View b) Simple View



c) Calories Consumption View

d) Augmented Reality View

Fig. 4. User Interface of the GreenBicycling

C. Riding Calorie Estimation

When the user arrives at rental spot, he can open GreenBicycling to start or to end riding journal, and the application will take corresponding action, opening or closing the sensors which collect the riding data. Since Near Field Communication (NFC) technology is integrated into the latest smartphone, an auto-trigger that GreenBicycling is automatically waken up or turned off when user arrives at a rental spot and touch the bicycle can be implemented in the future.

Because of the limited power and security policy, the smartphone background tasks are not suggested to access the sensor data frequently. Microsoft has implemented an energy-aware Windows Phone API that background tasks are only allowed to access a GPS cache refreshed every 15 minutes to trade-off energy consumption and usability of Location-based application. Routing Engine will fill user's track with the sparse sampled location and estimate the distance and velocity. Therefore we can pick the suitable η in TABLE I. to estimate the calories consumption. Finally, the user should fill his weight information in application setting page since it is required by calories estimation equation.

When the user borrows a bicycle from a rental spot, he can open GreenBicycling and start recording his travel. And when he ends his travel, he should close the task. As Fig. 4(c) shows, the cyclist can ask Riding Calories Estimation module about the amount of calories he burns and the riding mileage. The horizontal axis of the charts represents date. The longitudinal axis of the chart shown in Fig. 4 (c) represents calories consumption everyday. Its color gradual changes from red at the bottom to green at the top so that it can warn cyclist in the event of lack of physical exercise. From these charts, the cyclist will get intuitive understanding on how much physical exercise he gains from the rental system.

V. CONCLUSION AND FUTURE WORK

Traffic congestion is the culprit of pollution in many urban areas and citizens suffer from poor living environment. In order to relieve this stress, the Public Bicycle Sharing System (PBSS) provides a healthy riding life style for citizens. However, it lacks a friendly information service to user. This paper presents GreenBicycling, a smartphone-based Bicycle Sharing System, which provides essential features that will improve user experience of PBSS. The system provides not only map view but also augmented reality views for some cyclist with poor sense of direction. Furthermore, GreenBicycling uses quantitative measure to encourage user to use PBSS. The improved back propagation network is introduced to forecast the future information of rental spots to convenience the user. Our experiment shows that this model can eliminate the error caused by bicycles redistribution. Therefore, GreenBicycling provides reliable information to the cyclist to make his travel plan. In addition, we introduce a simple scheme to calculate user's calories consumption of riding with necessary sensor data collected from the smartphone. Through such quantitative measures and incentives, cyclist can know what he gains from the system. As a future work, we will implement intelligent travel plan recommendation based on our prediction model. We will make a user feedback survey regarding user satisfaction on GreenBicycling. On the other hand, we will propose a better calories consumption model and evaluate its accuracy since there is no cheap, customized and precise energy cost model for riding yet.

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