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Vehicle Positioning System Based on Cubic Spline Interpolation Using Statistical Analysis

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***Abstract* - Vehicle monitoring and positioning become an essential factor in road management to secure and safeguard the vehicular network, which influences the coupling of reliability on the advanced automobile technologies. Furthermore, to predict the exact location of a car in a given time is challenging, because it depends on a myriad number of elements. Moreover, knowing the position of a vehicle helps passengers as well as increase vehicle network security. In this paper, we propose a mathematical model to predict the position of a car from a prepopulated dataset using spline interpolation. More interestingly, the prediction point of a mobile vehicle will be presented without any help from real-time monitoring devices. Simulation of vehicle positioning is done using bus trajectory data in a university environment in the University of Malaya to verify the feasibility and benefit of the proposed approach. Accordingly, a process of evaluation has been performed based on a plethora of components and existing works to show the effectiveness of the proposed method.**

Keywords— Spline Interpolation, vehicle tracking, vehicle positioning

I. INTRODUCTION

The public transport system become one of the most important modes to fight against the increasing number of vehicles on the road. Furthermore, predicting the arrival time of the vehicle will improve the quality of services. That, in return, will bring more riders to enhance completeness with the other mode of transportation. However, most of the existing transportation modes are able to produce a real-time location of the vehicle with the help of the technology. Vehicles consist Global Positioning System (GPS) [1] to locate themselves in real-time on a map. Moreover, to transmit data vehicles use communication systems like General Packet Radio Services (GPRS), 3G, and 4G. As the vehicles travel with limited energy, preserving the power for a long time must be the goal of the system. However, to produce the location of the vehicle, it consumes enormous of unusual energy. On the other hand, nowadays vehicles use a lot of security[2] features such as authentication protection [3], intrusion detection[4] and so on, which consumes extra energies from the vehicles limited sources. Moreover, network issues cannot be negligible like no connectivity, poor signal, and change of the coverage of the base stations. Therefore, to provide the passengers with a direct perception of the vehicle arrival time with other information is essential without using vehicles reserved energy. A well-constructed prediction model can solve this problem. Over the past decades, much attention has been focused on this field. There are two types of vehicle position predictor in the research; these are 1) vehicle tracking based on devices such as GPS and 2) vehicle position predictors based on historical data and models.

In their paper, Tian *et al.* [5] have invented a vehicle tracking system from radar, GPS and DSRC communication equipment. Similarly, Pratama *et al*. [6] proposed a trajectory tracking and fault detection algorithm of Automatic Guided Vehicles (AGV) based on a multi positioning model. On the other hand, Feng *et al.* [7] proposed a vehicle location detection model based on omnidirectional vision. Additionally, Baek *et al.* [8] proposed a vehicle tracking system based on Kalman Filter which predicts the car's position on the next frame and Mean-shift which searches the vehicle with maximum similarity with the targeted car in the predicted location. On the other hand, researchers use machine learning techniques to indicate the position of a vehicle. On this occasion, Md Noor *et al.* [9] proposed the urban bus arrival time predictor by using support vector machine (SVM). However, the overall prediction research is further extended from ground vehicles [10] to underwater vehicles [11], surface water vehicles [12] and aerial vehicles [13].

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The construction of the rest of the paper is as follows. Part II presents the details of the proposed model. Results and discussion are shown in part III followed by the conclusion in part IV.

II. Proposed Vehicle Positioning System

All the vehicles follow a trajectory towards its destination. Many vehicles have the fixed route and time to observe and rest are random in the road. However, there is a pattern in the movement of unfixed destination cars. At the initial stage of designing the system, we have chosen the University of Malaya buses. The data has been gathered based on the bus's trajectory and position timing. Simultaneously, the mathematical model based on cubic spline interpolation is created to predict the position of an automobile. Finally, the collected data is used to examine the efficiency of the model. We have discussed the system architecture and vehicle positioning systems in the following parts.

A. System Architecture

To implement and test the effectivity of the proposed vehicle positioning system, we considered the university buses [14], which are maintained by the Department of Development and Asset Maintenance (JPPHB) at the University of Malaya. There are five bus routes (A, B, C, D, and E) currently running in the university to serve the students and staff. These buses have a fixed schedule and stoppage. Routes of some of the buses (A and B) are situated on the university premises, whereas others (C, D, and E) go out of campus to cover fixed areas. To further simplify, we have tested the proposed system on one of the routes of different buses. Fig. *1* represents the sample of the buses from the University of Malaya.

Fig. 1. University Malaya Buses [14].

As the buses roam on roads and sojourn on stoppages, they make a different pattern of movements along with the time. The trajectory point from the route of the basses is collected as latitudes and longitudes, and the time to reach on those points is gathered as per the local time (Malaysian time). A sample of the data has been shown in Table I, and the overall architecture is presented in Fig. 2.

B. Proposed Architecture

The system is based on the historical data of a vehicle. The model takes all the historical points along with the time of a car and is able to predict the location of a car on a given time from the travel period. To formulate that, we used cubic spline interpolation because of its effectiveness. Interpolation is a way of predicting a data point from a set of known and discrete set data points. Likewise, there are a number of ways to perform the interpolation like linear interpolation, piecewise constant interpolation, and polynomial interpolation. On the other hand, spline interpolation is a different kind of way for data interpolation using a special type of piecewise polynomial known as spline, to overcome the problems of Runge's phenomenon, which appears due to use of high degree polynomials. As well as that, cubic spline interpolation is to formulate an interpolation formula to provide a smoother interpolation function without the sharp corners.

Table I. Sample dataset of coordinate values with time for Bus B.

Latitude	Longitude	Time
3.121084	101.653533	11:30:50
3.119504	101.654565	11:31:40
3.121834	101.655983	11:32:50
3.12179	101.657557	11:33:47
3.121679	101.658411	11:34:05
3.12167	101.66041	11:34:50
3.123588	101.660635	11:35:20
3.126783	101.65976	11:36:27
3.131255	101.660244	11:37:47
3.131938	101.658124	11:38:25

To simplify our concept, the rest of the document will only focus on a bus trajectory of a single journey along with its timing. Furthermore, the location of a bus is measured by latitude and longitude, and both are represented as a single value as position P and time is shown as T.

Consider the n data points (x_1, y_1), (x_2, y_2), (x_3, y_3), …, (x_n, y_n) where x_i and y_i are discrete and representing position and time, respectively. Then, $f(x)$ can be represented as a cubic spline of a set of cubic polynomials, $f(x) > f_i(x)$, $where\ i = 1, 2, 3, \dots, n$, through the data points (x_1, y_1), (x_2, y_2), (x_3, y_3), …, (x_n, y_n).

$$f_i(x) = a_i + b_i(x - x_i) + c_i(x - x_i)^2 + d_i(x - x_i)^3 \quad (1)$$

To improve the prediction of location a vehicle, the previously mentioned function needs to be continuous, and the help of the following properties can do that.

1) Interpolation of the data points (x_i, y_i) and (x_{i+1}, y_{i+1}) on the spline sn is guaranteed by Eq. (2)

$$f_i(x_i) = y_i \text{ and } f_i(x_{i+1}) = y_{i+1} \text{ for } i = 1, 2, 3, \dots, n-1 \quad (2)$$

2) First-order derivative $f'(x)$ of x should be continuous on the interval $[x_1, x_n]$. Furthermore, the slopes of the neighbouring parts have to agree on the meeting by the Eq. (3)

$$f'_{i-1}(x_i) = f'_i(x_i) \text{ for } i = 2, \dots, n-1 \quad (3)$$

3) Second-order derivative f''(x) of x needs to be continuous on the interval $[x_1, x_n]$. Moreover, this phenomenon guarantees the smoothness by forcing the neighbouring spline to have the same curvature. (See Eq. (4))

$$f''_{i-1}(x_i) = f_i''(x_i) \text{ for } i = 2, \ldots, n-1 \quad (4)$$

To solve the Eq. (1), determining the coefficients are necessary. The determination of coefficients $a_i, b_i, c_i, and\ d_i$ are shown in the following steps.

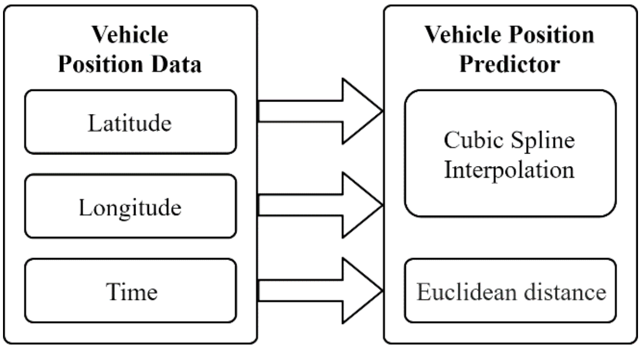

Fig. 2. Vehicle Positioning System.

Each spline meets on its adjacent points so the initial solution of the fiction should satisfy with its coordinates. Therefore, we consider (x_i, y_i) as a point on spline Eq. (1). Then, replacing x by x_i we will get,

$$f_i(x_i) = a_i \quad (5)$$

Combining Eq. (2) and Eq. (5), we get

$$a_i = y_i \quad (6)$$

Again, from Eq. (1) and Eq. (6), we conclude

$$f_i(x) = y_i + b_i(x - x_i) + c_i(x - x_i)^2 + d_i(x - x_i)^3 \quad (7)$$

The first-order derivative of Eq. (7) is

$$f_i'(x_i) = b_i + 2c_i(x - x_i) + 3d_i(x - x_i)^2 \quad (8)$$

The second-order derivative of Eq. (7) is

$$f_i''(x_i) = 2c_i + 6d_i(x - x_i) \quad (9)$$

Every sub-function must join at the data points, as every spline must be smooth across its entire interval.

$$f_i(x_i) = f_{i-1}(x_i) \quad (10)$$

Therefore, from Eq. (2) and Eq. (10)

$$y_i = f_{i-1}(x_i) \quad (11)$$

$$f_{i-1}(x) = y_{i-1} + b_{i-1}(x_i - x_{i-1}) + c_{i-1}(x_i - x_{i-1})^2 + d_{i-1}(x_i - x_{i-1})^3 \quad (12)$$

$$y_i = y_{i-1} + b_{i-1}(x_i - x_{i-1}) + c_{i-1}(x_i - x_{i-1})^2 + d_{i-1}(x_i - x_{i-1})^3 \quad (13)$$

For simplification of the equations, let k = $(x_i - x_{i-1})$ in Eq. (13).

$$y_i = y_{i-1} + b_{i-1}k + c_{i-1}\mathrm{k}^2 + d_{i-1}\mathrm{k}^3 \quad (14)$$

Finally after all the calculation and we will get the value of rest of the coefficients as follows:

$$b_i = ((y_{i+1} - y_i) / \mathrm{k}) - (\mathrm{k}(2SD_i + SD_{i+1})/6)) \quad (15)$$

$$c_i = SD_i / 2 \quad (16)$$

$$d_i = (SD_{i+1} - SD_i) / 6k \quad (17)$$

, where $SD_i = f_i''(x_i)$ and k = $(x_i - x_{i-1})$.

The system predicts the coordinate of a vehicle in a given time. We have used the Euclidian distance mechanism to predict more accurately on the trajectory of the vehicle. The Euclidian distance $d(p, q)$ for two coordinates' $p(x_1, y_1)$ and $q(x_2, y_2)$ is shown in Eq. (18).

$$d(p, q) = \mathrm{sqrt}(\ ((x_2 - x_1)\text{^}2) + ((y_2 - y_1)\text{^}2)) \quad (18)$$

Finally, the location of the vehicle is presented based on the nearest coordinate of the trajectory from the point which is identified by the cubic spline interpolation.

III. Results and Discussion

The illustration of the experiments has shown in this part of the paper. Furthermore, we have collected real-time data of the university bus B of the University of Malaya by visiting the site and with the help of a GPS device. Moreover, to prepare the model and simulate the architecture, we have used the powerful MATLAB simulator. For illustration, one instance of the trajectory of bus B is shown in Fig. 4. The performance of cubic spline interpolation on the taken path of the vehicle is represented accordingly in Fig. 5 and Fig. 6.

Algorithm 1 Vehicle positioning system

```
Input ← Coordinate values of the vehicle with arrival time.
Input ← Target time (T_tar) to identify the position of the vehicle.
Plot trajectory (Traj_v) of the vehicle.
Cubic Spline Interpolation(CSI_tlat) on time verses latitude.
Cubic Spline Interpolation(CSI_tlong) on time verses longitude.
Find target latitude(Lat_tar) on t from CSI_tlat.
Find target longitude(Long_tar) on t from CSI_tlong.
Identify minimum distance from (Lat_tar, Long_tar) to Traj_v using Euclidean Distance.
Output: Resultant coordinate (Lat_res, Long_res)
```

As per the previous statement, there are five different university bus routes at the University of Malaya. For the experiment of this project, we have considered bus B route, which starts and ends at UM Sentral visiting the Academy of Islamic Studies via KK10 (See Fig. 3). One of the contributors to this project was equipped with a GPS device, got into the targeted bus and collected the coordinates of the bus with the arrival time infraction randomly with an interval. Then, the data has preprocessed to use for the model. After that, those data were used to feed the mathematical model of the vehicle positioning system. Additionally, the model was tested against its accuracy with some pre-collected data of the same route. Furthermore, to identify the performance, we crosschecked the identified coordinated with the actual coordinates, the result was outstanding.

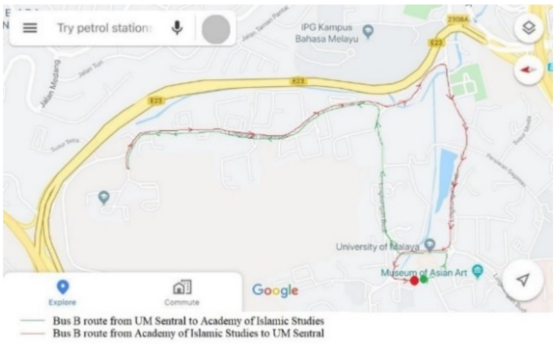

Fig. 3. Bus B trajectory on a map.

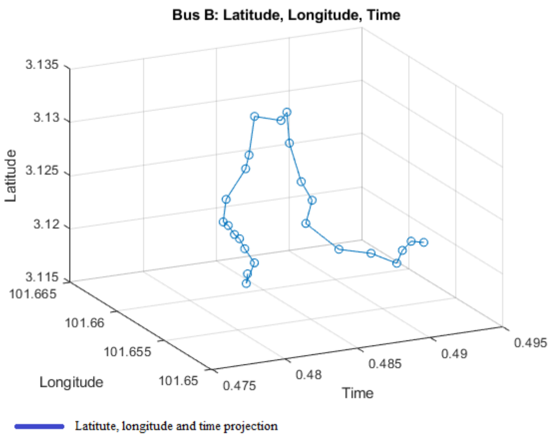

Fig. 4. Bus B trajectory projection in 3-D based on coordinate and time on the position.

To show the performance more accurately, we have performed the cubic spline interpolation on time versus latitude and time versus longitude separately at the same given time. Then the individual values of latitude and longitude are collected to point a single coordinate. Then, the model performs Euclidian Distance to measure the nearest location on the trajectory from the identified point. The working principle is shown in algorithm 1.

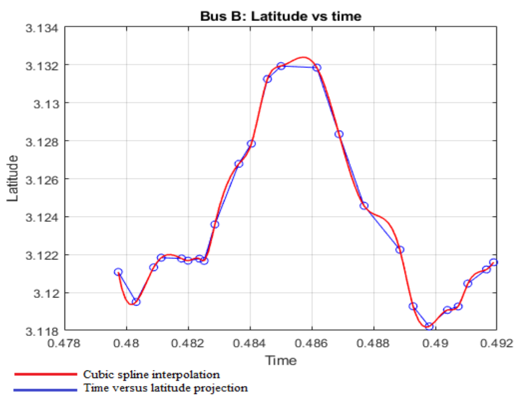

Fig. 5. Bus B time versus latitude projection along with cubic spline interpolation.

It has been shown that the runtime of the model in the simulator is 0.0019 seconds based on a dataset of 30 coordinates and Intel(R) Core(TM) i7-4770 CPU @ 3.40GHz processor. Moreover, the prediction of the vehicle lies within 4 meters from the actual location of the vehicle.

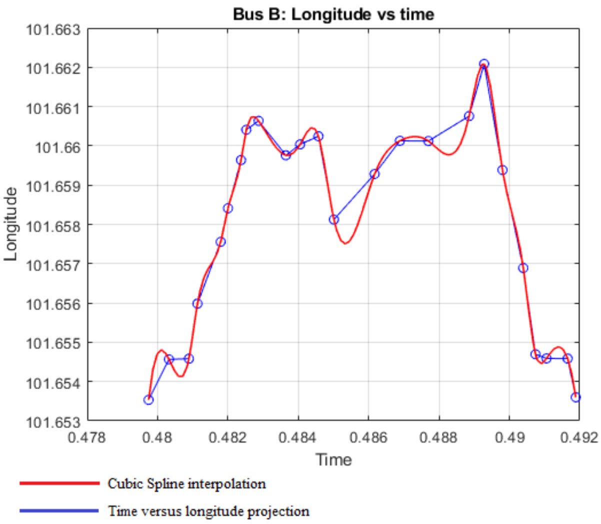

Fig. 6. Bus B time versus longitude projection along with cubic spline interpolation.

IV. Conclusion

To compete with the enhancement of different transportations and the congestion on the road, public transport catches more attraction in general. However, providing facilities and comfort toward their passengers are interesting factors for automobile industries. For that reason, it is necessary to show the position of the desired vehicles to legitimate users. On the other hand, high-end devices consume energy to produce the location of the vehicle. Therefore, the proposed mathematical model helps to identify the location of the vehicle without any detecting devices. The system not only helps to identify the location and help the passenger for predicting estimated time to arrive, but also it will definitely help to enhance the security of the vehicular network. In the future scope of the project, we will add more factors like weather, weekdays, weekends, a different time in a day and the number of passengers to the system to predict the location of a vehicle.

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