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Online Bus Arrival Time Prediction Using Hybrid Neural Network and Kalman filter Techniques

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ABSTRACT : *The ability to obtain accurate predictions of bus arrival time on a real time basis is vital to both bus operations control and passenger information systems. Several studies have been devoted to this arrival time prediction problem in many countries; however, few resulted in completely satisfactory algorithms. This paper presents an effective method that can be used to predict the expected bus arrival time at individual bus stops along a service route. This method is a hybrid scheme that combines a neural network (NN) that infers decision rules from historical data with Kalman filter (KF) that fuses prediction calculations with current GPS measurements. The proposed algorithm relies on real-time location data and takes into account historical travel times as well as temporal and spatial variations of traffic conditions. A case study on a real bus route is conducted to evaluate the performance of the proposed algorithm in terms of prediction accuracy. The results indicate that the system is capable of achieving satisfactory performance and accuracy in predicting bus arrival times for Egyptian environments.*

Keywords: *Intelligent transportation system, Neural network, Kalman filter, Arrival time prediction About five*

I. INTRODUCTION

Traffic plays an important role in modern urban society. Because of the limitation of the traffic resources, those increments will lead to urban traffic congestion. In order to relieve the congestion, the governments all around the world provide funding and support to develop public traffic systems and build traffic applications, such as subway system, signal control systems, traffic information management system, electronic toll collection systems, etc. which fall under intelligent transportation system.

This paper concern is the part of research project called Transportation Management and User Awareness (TMUA) that research project is financially supported by NTRA to interconnect public transportation vehicles and bus stations with a central office to monitor the underlying vehicles. Based on the collected data and by analyzing road condition, accurate arrival times could be computed and transmitted to all relevant stations. Waiting time for the next bus(s) to arrive will be announced on screens and via audio speakers (in Arabic) to commuters on the bus station. Passengers in buses will be notified of the next bus stop using visual and audio announcements. Achieving these main features will cause major improvement in public transport convenience and safety.

It will also allow the central offices to manage effectively their resources (mainly busses) through better route planning in relation to peak hours and congested zones. In the proposed system, virtually all data that are collected and stored are multi-dimensional. Typically, ranges of features are measured at a particular time or condition and stored as a complex data object. The data come in the form of a vector of real values. Different approaches use the spread of the data to suggest a new basis by choosing the directions that maximize the variance of the observations. If there are significant correlations between the different features, the number of features required to capture the data will be decreased.

Arrival-time calculation depends on vehicle speed, traffic flow and occupancy, which are highly sensitive to weather conditions and traffic incidents. These features make travel-time predictions very complex and difficult to reach optimal accuracy. Nonetheless, daily, weekly and seasonal patterns can still be observed at a large scale. For instance, daily patterns distinguish rush hour and late night traffic, weekly patterns distinguish weekday and weekend traffic, while seasonal patterns distinguish winter and summer traffic. The time-varying feature germane to traffic behavior is the key to travel-time modeling.

This research will assess what traffic, transit and freight data are available today from various sources, and consider how to integrate data from busses acting as "probes" in the system. Some obvious information is obtained easily though traditional query operation from traffic database, but deeper information that hides in the traffic database is difficult to be discovered. Deep level information usually contains characteristics of data and forecast information of data development tendency.

Therefore, we are concerned with how to develop a powerful data-mining algorithm and apply it on the available data. In addition, a model-based predictor based on implementing a Kalman filter could be employed when the data-mining algorithm might be failed. In this paper, we propose hybrid Neural Network and Kalman filter Techniques to predict the bus arrival time. This paper is organized as follows. literature review presented in Section 2. Bus arrival time prediction methods are illustrated in Section 3. The proposed scheme for time prediction is presented in Section 4. Simulation results and discussions are given in Section 5 and finally conclusions are drawn in Section 6.

II. LITERATURE REVIEWS

In this section, some relative previous works related with bus travel time prediction are summarized. The main idea of the time prediction is based on the fact that traffic behaviors possess both partially deterministic and partially chaotic properties. Forecasting results can be obtained by reconstructing the deterministic traffic motion and predicting the random behaviors caused by unanticipated factors. Suppose that currently it is time t. Given the historical data f(t-1), f(t-2),…, and f(t-n) at time t-1, t-2,…, t-n, we can predict the future value of f(t+1), f(t+2), … by analyzing historical data set. Hence, future values can be forecasted based on the correlation between the time-variant historical data set and its outcomes. The bus arrival time prediction models can be classified into the following three main items: mathematical algorithms (Historical Approach, Real-Time Approach and Statistical Models), Kalman Filter model with historical data, and Artificial Neural Network(ANN) model which will discussed in the next section.

In 1999, Lin and Zeng developed a mathematical algorithm to provide real-time bus arrival information [1]. They considered schedule information, bus location data, the difference between scheduled and actual arrival time, and waiting time at time-check stops in their algorithm. Their algorithm could not consider traffic congestion and dwell time at bus stops. At the same year, Ojili developed a bus arrival time notification system in College Station [2]. The model breaks the bus route into one-minute time zones. The bus arrival time at a given stop was predicted by counting the estimated number of the one-minute time zones between current location and the given stop. The model had the same issues as Lin and Zeng's. Also, it does not consider the traffic congestion and dwell time at bus stops.

Wall and Dailey are the first authors who use Kalman Filter model to predict bus arrival time [3]. In their algorithm, they used a combination of both global position system(GPS) data and historical data, they used a Kalman filter model to track a vehicle location and used a statistical estimation technique to predict travel time. It was found that they could predict bus arrival time with less than 12% error. However, they did not explicitly deal with dwell time as an independent variable. In 2003, Shalaby and Farhan proposed another bus travel time prediction model by using Kalman filtering technique [4].

In the model, they considered the passenger information at each bus stop. However they predicted dwell time only at time check points, not at every bus stop. Due to the capability to solve complex non-linear relationships, artificial neural network model (ANN) had been used to model the transportation problems. The models had shown better results than those of existing. In 2002, Chien et al developed an artificial neural network model to predict dynamic bus arrival time in New Jersey. Considering the back-propagation algorithm is unsuitable for on-line application, the authors developed an adjustment factor to modify their travel time prediction by using recent observed real-time data. However the dwell time and scheduled data were not considered in their model [5].

In 2004, Jeong and Rilett provided a historical data based model, regression models and Artificial Neural Network (ANN) models to predict bus travel time by considering traffic congestion, schedule adherence and dwell times at stops [6]. In 2006, Ramakrishna et al proposed a multiple linear regression and an ANN model to predict bus travel times. In their model they considered real time GPS data of bus locations [7].

In 2009, Suwardo et al. proposed a statistical neural network model to predict the bus travel time in mixed traffic, while considering bus travel time, distance, average speed, number of bus stop, and traffic conditions. In their paper, they assessed those factors and studied the relationship mode between the factors and bus travel time [8].

In 2011, Feng Li et al. proposed a statistical model to predict the bus arrival time based on proposed linear [9]. In their paper, they had considered all of evaluated factors, such as departure time, driver characteristics, dwell time, intersections, traffic conditions etc.

Among the above models, artificial neural network model and statistical neural network model have shown advantage than other models, such as Kalman Filter model, historical average model, auto-regressive integrated moving average (ARIMA) model and exponential smoothing model. However the parameters for those models are hard to determine because it need more historical data and will cost us more time. Although the models can provide relative bus arrival prediction time, but it is hard for us to explain the mechanism for them. Because of those reasons, in this paper we will provide a Hybrid Kalman filter with Neural network approach to forecast bus arrival time.

III. Bus Arrival Time Prediction methods:

Bus arrival time prediction has been studied by many in recent years, different approaches where studied for time prediction such as:

Historical Approach: Predicts the travel time at a particular time as the average travel time for the same period over different days.

Real-Time Approach: Predicts the travel time at the next time interval to be the same as that in the present time interval, this approach assumes that the bus travel time trend fluctuate within a narrow range which is impossible for actual traffic trend, such as incidents, congestion and other unpredictable traffic conditions.

Statistical Models: Predict the bus arrival time based on a function formed by a set of independent variables.

Model-Based Approaches: The Kalman Filter algorithm outperformed all other developed models in terms of accuracy, demonstrating the dynamic ability to update itself based on new data that reflected the changing characteristics of the transit-operating environment. So that algorithm was used to update the state variable (travel time) continuously as new observations became available.

Machine Learning Techniques: Artificial neural network (ANN) is one of the most commonly reported techniques for traffic prediction mainly because of their ability to solve complex non-linear relationships [10]. Table 1 shows a comparison between different time prediction techniques and summarizes the approaches of estimating the bus travel time.

Table 1: Comparison between different time prediction techniques

Technique	Remarks	Delay considered
Historical approach	Predict the travel time at particular time as the average travel time for the same period historically	no
Real-time approach	Assume the future travel time to be the same as the present one	no
Time series analysis approach	Assume the historical patterns will remain same in the future	no
Statistical models	Predict the dependent variable based on a function formed by a set of independent variables	Yes,
Machine learning techniques	Prediction based on example data .Need large database for an accurate prediction	no
Model-based approaches (Kalman filter)	Establish relationships between the variables and then corroborates using field observation .Not site specific or data specific	yes

IV. The Proposed Prediction Time Method

In the proposed system, two models are suggested for bus arrival time prediction:
1- Machine Learning technique (ANN) for off line estimation using previously collected data from traffic database.
2- Model- based approach (Kalman filter) for online calculations in case of wide deviation between offline estimation and real time data (special cases). Figure 1 shows the preliminary flowchart of the proposed algorithm.
In what follows the basic steps of the underlying algorithm are explained:

V. Data Collection

In the proposed system, virtually all data that are collected and stored are multi-dimensional. Typically, a range of features is measured at a particular time or condition and stored as a complex data object. The data comes in the form of a vector of real values.

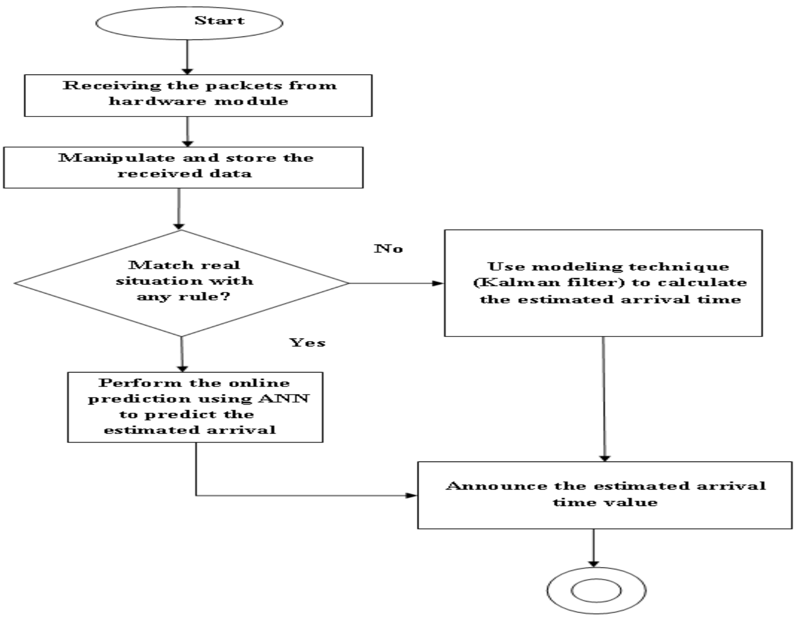

Figure 1: Flowchart of the proposed prediction time algorithm

VI. Proposed Neural Network

Neural networks are statistical models of real world systems, which are built by tuning a set of parameters. These parameters are seen as inputs to an associated set of values: the outputs. The process of tuning the weights to the correct values – training – is carried out by passing a set of examples of input-output pairs through the model and adjusting the weights in order to minimize the error between the answer the network gives and the desired output. Once the weights have been set, the model is able to produce answers for input values, which were not included in the training data [11, 12]. The used neural network, Figure 2, consist of four layers: input, two hidden, and output layer. The Input Layer of the proposed neural network has seven nodes. In this configuration, a double hidden layer is used. The first hidden layer has 10 nodes and the second hidden layer has 3 nodes while the output layer has only one node.

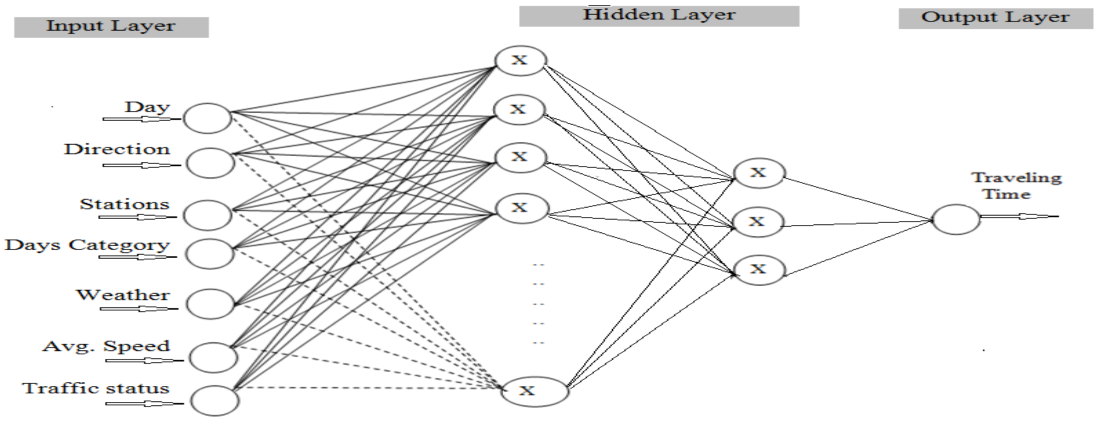

Figure 2: Proposed neural network structure

VII. PROPOSED KALMAN FILTER PREDICTOR

The Kalman filter, also known as linear quadratic estimation (LQE), is an algorithm which uses a series of measurements observed over time, containing noise (random variations) and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those that would be based on a single measurement alone. More formally, the Kalman filter operates recursively on streams of noisy input data to produce a statistically optimal estimate of the underlying state. The Kalman filter uses a system's dynamics model (e.g., physical laws of motion), known control inputs to that system, and multiple sequential measurements (such as from sensors) to form an estimate of the system's varying quantities (its state) that is better than the estimate obtained by using any one measurement alone.

The Kalman filter estimates a process by using a form of feedback control: the filter estimates the process state at some time and then obtains feedback in the form of (noisy) measurements. As such, the equations for the Kalman filter fall into two groups: time update equations and measurement update equations. The time update equations are responsible for projecting forward (in time) the current state and error covariance. Figure 3 illustrate Kalman filter operations.

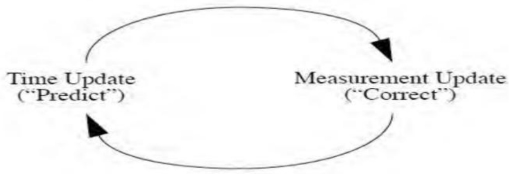

Figure 3: Proposed Kalman Filter structure

The modified Kalman Filter algorithm used in the current research project, the last three similar days in the last three weeks historical data of actual running times between links at the instant k+1 and the last running time observation at the instant (k) on the last day are used to predict the bus running time at the instant (k+1).

The Kalman Filter equations that are used for time prediction are:

$$g(k+1) = \frac{e(k) + VAR[local_{data}]}{e(k) + 2 \cdot VAR[local_{data}]}$$

$$a(k+1) = 1 - g(k+1)$$

$$e(k+1) = VAR[local_{data}] \cdot g(k+1)$$

$$P(k+1) = a(k+1) \cdot art(k) + g(k+1) \cdot art_1(k+1) \quad \text{-----------------------------------(1)}$$

Where:

g = filter gain, a = loop gain, e = filter error, p = prediction,

art (k) = running time at the instant (k) on the last day at instant (k)

art1 (k+1) = actual running time of the similar day at instant (k+1)

VAR [local data] = prediction variance, and

VAR [local data] = last three similar days in the last three weeks "art3 (k+1), art2 (k+1) and art1 (k+1)" variance.

$$VAR[local_{data}] = VAR[art_1(k+1), art_2(k+1), art_3(k+1)] \quad \text{-----------(2)}$$

The variance VAR [local data] is calculated at each instant k + 1 using the actual running time values for last three similar days in the last three weeks: art1 (k + 1), art2 (k + 1) and art3 (k + 1).

Where:

art1 (k+1): actual running time of the bus at instant (k+1) at the similar day on the previous week.

art2 (k+1): actual running time of the bus at instant (k+1) at the similar on two weeks ago.
art3 (k+1): actual running time of the bus at instant (k+1) at the similar on three weeks ago.
The definition of the variance for a random variable is:

$$VAR[X] = E[(X - E[X])^2]$$

$$E(X) = Avg(art) = \frac{art_1(k+1) + art_2(k+1) + art_3(k+1)}{3}$$

------------------(4)

Now the variance can be calculated as given in the following equations:

$$\Delta_1 = [art_1(k+1) - avg(art)]^2$$
$$\Delta_2 = [art_2(k+1) - avg(art)]^2$$
$$\Delta_1 = [art_3(k+1) - avg(art)]^2$$

------------------(5)

$$VAR\,[local_{data}] = \frac{\Delta_1 + \Delta_2 + \Delta_3}{3}$$

VIII. SIMULATION RESULT

To determine the prediction times of a moving bus to the downstream bus stations, the GPS readings of each equipped bus need to be projected onto the underlying transit network. In a digital transit network model, bus routes are represented by a sequence of line features as an approximation to their true geographical composition.
Such straight line approximations are usually not accurate enough for tracking purposes. To ensure representation accuracy. The end points of each link, also called nodes, are specified by their longitudes and latitudes. All links and nodes are numbered according to the sequence in which the bus passed, and then they are recorded into a file for later use.
The neural network is learned through the creation of a set of random data for one route consisting of 6 stations from S0 to S5. Table 2 shows the ranges that were used for creating the random data, where "Sn, n=0,1,2,…,5" refers to station number.

Table 2: The ranges used to create random data

Day		s0-s1	s1-s2	s2-s3	s3-s4	s4-s5
Sunday	M	5-->7	5-->7	8-->12	4-->6	3-->5
	A	7-->10	7-->10	15-->18	5-->8	4-->7
Monday	M	5-->7	5-->7	8-->12	4-->6	3-->5
	A	7-->10	7-->10	15-->18	5-->8	4-->7
Tuesday	M	7-->11	7-->11	10-->14	6-->8	5-->7
	A	9-->13	9-->13	17-->20	7-->10	6-->9
Wednesday	M	7-->11	7-->11	10-->14	6-->8	5-->7
	A	9-->13	9-->13	17-->20	7-->10	6-->9
Thursday	M	5-->7	5-->7	8-->12	4-->6	3-->5
	A	9-->14	9-->14	18-->21	8-->11	7-->10

The simulation was performed using Matlab, Figure 6 shows the result of the proposed route. The simulation results give acceptable mean square error in the range of 1.2 minute on the whole route (max. 37min) .

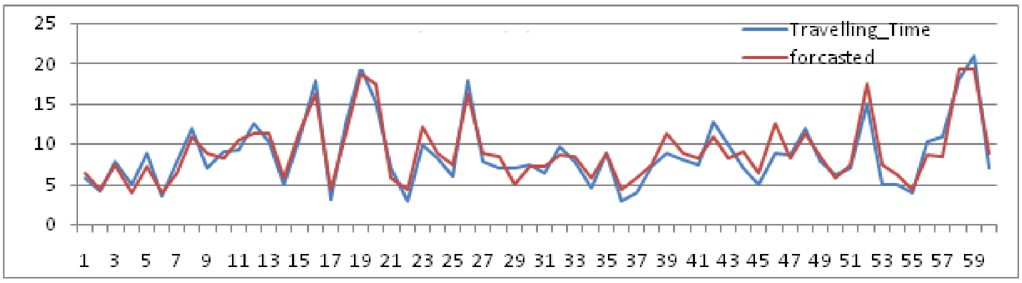

Figure 6: Neural network results

For Kalman filter testing, The example previously used to test the ANN is also applied to test the Kalman filter algorithm. Figure 7 shows the Kalman performance versus the actual running time. The simulation results give acceptable mean square error in the range of 1 minute on the whole route .

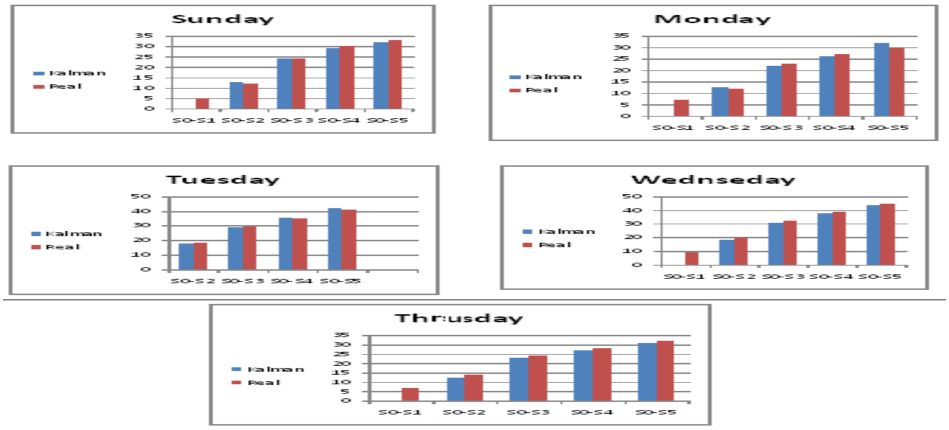

Figure 7 Kalman filter algorithm vs. real arrival time

The comparison between the actual, neural, and Kalman filter results are shown in figure 8.

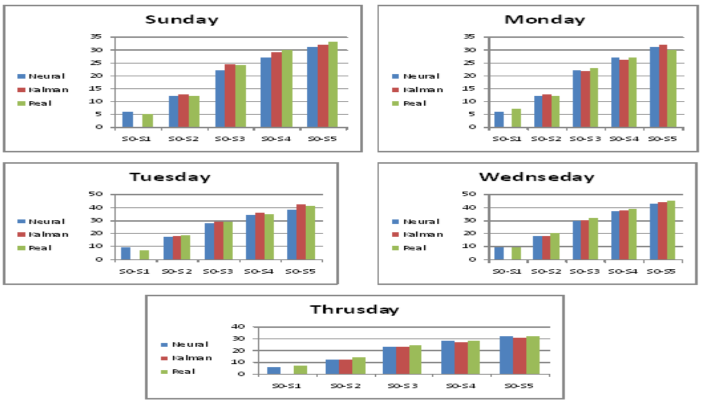

Figure 8 : Comparison between the actual, neural, and Kalman filter results

Figure 8 shows the predicted arrival times at individual bus stations for different time periods and days using neural and proposed Kalman filter techniques. As shown in the figure, there is a variation in prediction accuracy with respect to time period and stations due to the effect of traffic time along the route segment. In the test scenario the firmware switch between two different modes of operation to test the different arrival time calculation algorithms.

Normal mode operation: In this mode, the expected arrival time of station are selected within acceptable deviations from that calculated using ANN algorithm. The firmware loops among the bus stations using the estimated arrival time previously selected. The sever sends the estimated arrival time to the stations using the ANN calculated values.

Congestion mode: In this mode, the expected arrival time of station are selected with wide deviations from that calculated using ANN algorithm. The firmware loops among the bus stations using the estimated arrival time previously selected. In this case, the server will calculate the estimated arrival time using Kalman filter algorithm.

IX. CONCLUSIONS

In this paper, a model-based technique is proposed to predict the expected bus arrival times at individual bus stops along a service route. The proposed prediction algorithm combines real-time location data from GPS receivers which built in buses with average travel speeds of individual route segments, taking into account historical travel speed as well as temporal and spatial variations of traffic conditions. The proposed method is a hybrid scheme that combines the robustness of neural network with the reliability of Kalman filter. A case study on a real bus route is conducted to evaluate the performance of the proposed algorithm in terms of prediction accuracy. The results indicate that the proposed system is capable of achieving satisfactory accuracy in predicting bus arrival times.

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