Avrupa Bilim ve Teknoloji Dergisi
Özel Sayı, S. 522-529, Eylül 2020

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Special Issue, pp. 522-529, September 2020

Research Article

Travel Time Prediction with Bluetooth Sensor Data in Intelligent Traffic System (ITS)

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(1st International Conference on Computer, Electrical and Electronic Sciences ICCEES 2020 – 8-10 October 2020)

(**DOI:** 10.31590/ejosat.829619)

ATIF/REFERENCE: Civcik, L. & Koçak, S. (2020). Travel Time Prediction with Bluetooth Sensor Data in Intelligent Traffic System (ITS). *European Journal of Science and Technology*, (Special Issue), 522-529.

Abstract

Travel time plays a major role in handling the traffic rate. Bluetooth technology is one of the approaches this time observable. Traffic tracking, vehicle determination on a certain route, and travel time information can be obtaine dusing the bluetooth data gathered using this tool. The Bluetooth technology will be used to analyze certain features affecting travel time results. Highway travel time can be used as a new and efficient data collection tool through the bluetooth sensors which are widely used today. The central control software system consists of a comprehensive system for storing and organizing data at a central location, processing data in vehicles and displaying it to drivers. The central system architecture can be used to display congested road data to the driver, including scenarios, text messages and visuals, identified by traffic information message signs (VMS), which are also linked to the system on the particular highway via a data fusion process in line with data from a variety of sources, for example sensors. Providing information about travel time distribution, both average and variance, will play a more effective role in drivers' high likelihood of arriving on time and in selecting efficient routes. In order to determine the travel time flow, an inhomogeneous data fusion tracking is performed by combining the scattered collected data with distance detectors. With this method preferred in the research, road travel time flows are determined with the help of sensors. The travel time of the roads without sensors is obtained from the data of GPS-based service providers. In addition to the travel time flow, the Dempster-Shafer theory is combined with the travel time results from the distance sensors. Based on the travel time results obtained, the method of improvement in travel time flow has been developed.

Keywords: Travel time, Public transport, Traffic management, Bluetoth sensor, Traffic time estimation

Akıllı Trafik Sistemlerinde (ITS), Bluetooth Sensor Verileri Yardımıyla Seyahat Süresi Tahmini Gerçekleştirme

Öz

Trafik yoğunluğu yönetimi için seyahat süresi önemli bir rol oynar. Bu süreyi saptayabilecek yöntemlerden biri de bluetooth teknolojisidir. Bu yöntemle toplanan bluetooth verileri ile; trafik izleme, belirli bir rotadaki araçları belirleyebilme ve seyahat süresi gibi bilgiler elde edilebilmektedir. Bluetooth teknolojisi ile seyahat süresi verilerini etkileyen belirli özellikler analiz edilmiştir. Günümüzde aktif olarak kullanılan bluetooth sensörleri aracılığıyla, otoyol seyahat süresi yeni ve etkili bir veri toplama aracı olarak kullanılabilmektedir. Merkezi kontrol yazılım sistemi, merkezi konumda verileri toplamak, biçimlendirmek, araçlardaki verileri işlemek ve sürücülere sunmak amacıyla bütünsel bir sistem içermektedir. Merkezi sistem tasarımı, bir veri kaynaştırma işlemi yoluyla, bir dizi kaynaktan örneğin sensorlerden gelen veriler doğrultusunda ilgili otoyol üzerinde yine sisteme bağlı olan trafik bilgilendirme mesaj işaretlerine (VMS) tanımlanan senaryolar, metin mesaj ve görseller olmak üzere sürücüye ilgili tıkanık yol verilerini sunmak için kullanılabilmektedir. Hem ortalama hem de varyans olmak üzere seyahat süresi dağılım bilgilerinin sağlanması, sürücülerin zamanında ulaşma olasılığının yüksek olması ve güvenilir yol seçimlerinde daha etkili bir rol oynayabilmektedir. Seyahat süresi akışını belirleyebilmek için dağınık toplanan verileri, mesafe detektörleriyle birleştirerek homojen olmayan bir veri füzyon takibi yapılmaktadır. Yapılan çalışmada tercih edilen bu yöntemle, yol seyahat süresi akışları sensörler yardımıyla tespit edilmektedir.

Sensör bulundurmayan yolların ise seyahat süresi tespiti, GPS tabanlı servis sunucularının verilerinden elde edilmektedir. Seyahat süresi akışında ek olarak Dempster-Shafer teorisi, mesafe sensörlerinden elde edilen seyahat süresi sonuçları ile birleştirilmiştir. Elde edilen seyahat süresi sonucuna bakarak, yol seyahat süresi dağılımlarını iyileştirme yöntemi geliştirilmiştir.

Anahtar Kelimeler: Trafik yönetimi, Bluetooth sensörü, Trafik süresi tahmini, Seyahat süresi

1. Introduction

The "travel time" flow time for a round trip between two traffic points lets drivers schedule their journeys better. The travel time data is an important parameter in the network of intelligent traffic systems, the awareness and foresight of traffic requests, traffic density simulation, traffic time monitoring, event detection, density management and efficient route selection.

Travel time is a complex, spatial parameter which is difficult for the entire travel flow to be calculated directly. Travel time is directly determined by sensors from vehicles traveling along a road path, connected to specified points. Automatic vehicle identification (AVI), Automatic number-plate recognition Systems, Signature Matching Detection Systems, Platoon Recognition System, Global Positioning Systems (GPS), cell phones and Bluetooth sensors are one of the common methods used in travel flow analysis.

While today these sensors are implemented, the calculation of travel time has several downsides. They do not have numbers, occupancy and flow statistics, require user involvement, have privacy concerns and can be restricted to specified traffic segments.

More and more development is ongoing for applications for Bluetooth, travel time measurement. Preliminary western studies have shown Bluetooth's cost-effectiveness benefits in spatial sensing under homogeneous traffic conditions [1]. Agencies such as the United States Department of Transportation in Illinois [2] and Houston Transtar use Bluetooth sensors to gather information on travel times. This research examines the feasibility of traffic data sources for Bluetooth sensors as road traffic conditions in Turkey aim to provide traffic and protection.

Using Bluetooth sensors, this can be used to measure vehicle travel times with bluetooth devices. Therefore, understanding the percentage of tools that data can be collected using this method, i.e. analysis of the penetration rate, is important. It is also important to know the class-based distribution of the tools which collect data from. Highways; Light and heavy two vehicles (bikes, motorcycles), three (three-wheelers) and four-wheelers (cars) share a dense population of pedestrians.

This study determines by performing penetration analysis, the class-based distribution of Bluetooth-based data. In addition, a method for estimating the flow travel time from sampled data has been developed.

2. Material and Method

Traffic conditions are measured using data from different devices, from conventional inductive loops to advanced Bluetooth MAC Scanners. Different methods have been proposed to determine travel time (or speeds) ([3], [4], [5] - [8]) and intensity ([9] - [11]) from the information of loop sensors. Bluetooth connects different devices wirelessly at close distances using low power radio waves(1-100 m).The Bluetooth system uses an electronic signature of 12 digits, called the address of the Media Access Control or MAC. For each vehicle, that acts as an electronic alias. This question forms a constant connection between MAC IDs. The MAC ID's anonymity guarantees privacy [2] and is used as a handle for collecting traffic information.

In our research, privacy breaches have been removed by replacing the user-captured MAC IDs with a random number created automatically by the Bluetooth sensor.

Travel time from Bluetooth sensor data is determined by matching the MAC IDs at the two locations. Most recent Bluetooth studies for traffic applications focus on Bluetooth data quality control and average speed or origin-destination estimate ([1], [2]). In most of these studies, the sampling rate or penetration rate captures just a percentage of the traffic flow, and is used as a source of traffic data.

For example, in a study conducted at the University of Maryland, a low sampling rate of 2% to 4% was observed for one Bluetooth per hour [1]. The timing of travel obtained using data from Bluetooth detectors was shown in this study as comparable with the data obtained using GPS.

Our research also suggests a two-step method for filtering travel time to determine upper and lower limits from the distribution of travel time. The accuracy of the measured travel time has been reported to be better with the distance between the two Bluetooth detectors and decreasing vehicle velocity.

Stevanovic and Martin [12] compared the travel times calculated by Bluetooth MAC readers to those obtained using floating vehicles equipped with the GPS. He recorded that for 83 per cent of cases, travel times from Bluetooth readers did not significantly (by 95 per cent) shift from GPS floating vehicle travel time.

Wang et al. [13] showed that the travel time obtained from the Bluetooth sensors and calculated from loop detectors was approximately similar with sampled data.

Welsh et al. [14] worked to boost communication times for Bluetooth technology between mobile devices and suggested the development of a mesh network of Bluetooth-connected devices.

Ahmed et al. [15] further discussed the idea of using Bluetooth technology to build a static data gathering network for ITS. In several research studies the Bluetooth detection technology has been shown to be effective [15, 16]. Path and heavy path tests, methodologies focused on Bluetooth sensor data processing, intrusive approaches such as loop sensors, and Floating Vehicle Data ([1], [17]-[19]).

Sadabadi vd. Using the relationship between vehicle length, average speed and travel time, [20] showed that taking into account the upper limits of errors, the travel time evaluation error could be negligible when the average speed was 45 km / h and the distance 2–3 miles between two sensors. Quayle et al. ([17], [18]) used a shifting standard deviation to determine the upper and lower travel time limits determined by a Bluetooth sensor [21].

Jaume et al. [22] studied the quality of data generated by Bluetooth and Wi-Fi detection of mobile devices to observe time dependent Kalman Filtering-based Source Target matrices.

Sawant et al. [23] used the wireless sensor network principles and Bluetooth protocols to establish a new approach that enhances road travel safety.

Bullock et al. [24] investigated the feasibility of Bluetooth in calculating the time spent traveling through the security screening checkpoint to the airport entry point, waiting in long queues for security scanning. As with other methods of calculating travel time, sources of error exist and external data points need to be reviewed to ensure accurate travel times are recorded. Any errors can occur as a result of signal delay and non-uniform traffic flow in the heavy traffic hotspot Bluetooth travel time determinations [25]. 10.24s is needed to complete the Bluetooth interrogation process, which produces a broad source of error and causes incorrect travel time measurements, but as the distance between Bluetooth stations increases, the measurement error decreases [(26],[27]). In recent years, several researchers have attracted the interest of Bluetooth and cell phone applications in estimating the travel time. As a result, several studies for detecting and addressing outliers were presented ([25], [28]). Point-to - point sources of data such as Bluetooth have been widely documented as self-sufficient when it comes to travel time prediction ([29],[30]). The often-created presumption, however, is that the data samples are large enough to quantify the relevant statistics [31]. On the other hand, the travel time estimation method includes a variety of methods for collecting data.

Steven et al. [32] compared Radio Frequency Identification (RFID), Bluetooth sensors, and data acquired by the software company INRIX with "absolute direction" travel time data obtained from GPS-based navigation systems probe vehicles. Many of the above-mentioned studies were performed in compliance with the more homogenous European traffic norms.The fundamental rules of using Bluetooth for various kinds of traffic conditions, travel time forecasts stayed constant, Turkey needs to make significant improvements to ensure certain requirements are followed.

2.1. Data

Enabled and mounted in two places, Bluetooth sensors are connected to laptops with "Batch Interface Program" software. When the sensors move by a vehicle with Bluetooth system, the program automatically records the MAC ID and time stamp (Figure 1). Matching pairs were determined using data obtained from two sources.

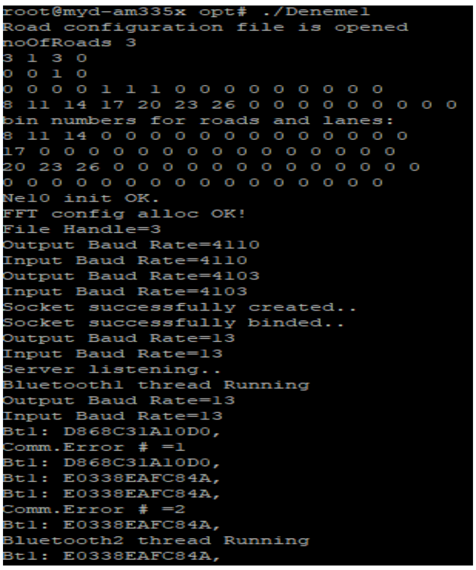

Figure 1 - List of MAC IDs Collected from Vehicles

The discrepancy between the arrival timestamps is acknowledged as the vehicle's travel time at the two locations obtained for the mutually compatible MAC ID. The total number of cars, the categorization and the actual value of travel time were also videotaped to obtain real value for all data collection operations manually, and this information was useful for leakage, class classification and estimated travel time verification.

Data were composed during two point traffic periods (08.00-12.00 and 15.00-19.00) for the analysis and also one more day (08.00-19.00) for vehicle type identification.

The calculated flow travel time obtained from the simulation studies was used for verification as it was tiring to collect data from the field and was time consuming. The data was created using the batch interface program. The simulation was carried out on 16-19 August 2020 using actual field flow knowledge obtained from an automated sensor.

Travel time, grouped speed, and flow information was created for 24-hour intervals on both days and the flow was used to measure, model, and validate travel time.

2.2. Sampling Rate Analysis

Real Bluetooth sensor traffic volume, also known as the sampling rate [2], is a significant predictor for determining the adequacy of the sample size for analysis. Analysis of the penetration levels at the entry and exit locations was carried out separately. The number of Bluetooth-captured vehicles at each position was derived from the raw data collected using the Bluetooth sensor. By manually counting the vehicles in the video the total number of vehicles going through each of these locations was obtained. During the entire data collection duration such counts were made at intervals of 5 minutes.

The division of the number of samples collected by Bluetooth over a given 5-minute period into the total vehicle flow was taken as the rate of penetration for that time. Figure 2 shows the maximum and minimum rate of penetration at two separate locations in the morning and evening hours.

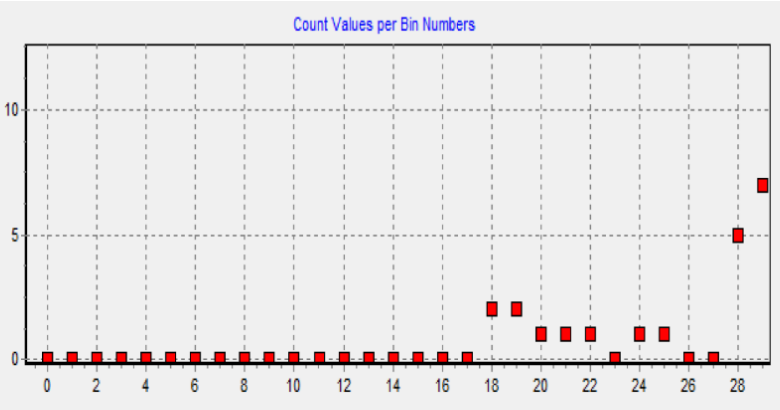

Figure 2 - HSV Speed and 3W Speed Distribution Graph

3. Results and Discussion

3.1. Estimating Travel Flow Time

In order to understand the suitability of Bluetooth technology in road travel time estimation, it is necessary to know the distribution of Bluetooth sensors to different vehicle groups. Four main vehicle groups are debated in this research:

- Two wheels (2W),
- Three wheels (3W),
- Light engine vehicles (LMV) and
- Heavy motor vehicles (HMV).

Which is 5 percent of the average penetration rate in the conditions of Turkey and in this report, Bluetooth High Speed Tools (HSV), which are grouped primarily 2W penetration rate capture and LMV is understood from the class of analysis and classification report. Therefore, the average travel time of HSV is calculated by measuring it via Bluetooth. In order to determine the entire road travel time, firstly the travel times of slow moving vehicles should be calculated from the travel times in the data collected.

The average HSV velocities were determined using the known distance between data collection points as follows, based on the HSV average travel times measured.

$$V_{HSV} = D_{12}/T_{Bluetooth}, \quad (1)$$

$T_{Bluetooth}$, here is the travel time determined by the Bluetooth sensor, the high-speed vehicle V_{HSV} speed and the distance between the two detector stations is D_{12}.

From this HSV velocity the velocity of the whole flow has to be calculated. The composition of traffic in the research result was found to be 25 percent 2W, 5 percent 3W, 45 percent LMV and 25 percent HMV. And the average weighted velocity of the whole flow can be written as:

$$V_{stream} = 0.45V_{2W} + 0.06V_{3W} + 0.02V_{HMV} + 0.47V_{LMV}, \quad (2)$$

V_{2W} is the speed of 2-wheelers, V_{3W} speed of 3-wheelers, V_{HMV} speed of heavy motor vehicles, V_{LMV} speed of light motor vehicles and V_{stream} average flow rate.

The corresponding travel time for flow may be expressed as follows:

$$T_{stream} = D_{12} / V_{stream}, \quad (3)$$

T_{stream} is the stream travel time of the road.

Weighted linear regression utilized travel time data from HSV to estimate the speed of slow moving 3W and HMV. 3W/HMV speed was treated as dependent variable and HSV speed as independent variable.

$$V_{3W} = \alpha_1 VHSV, \quad (4)$$

$$V_{HMV} = \alpha_2 VHSV, \quad (5)$$

α_1 is the coefficient obtained from the 3W-HSV regression; it is the coefficient of α_2 obtained from the HMV-HSV regression.

In addition to this, in linear regression, every data point is considered to have exactly the same information, and this may not always be the case. In this case, weighted linear regression is used to reduce the error by assigning a weight to each point that governs its effect on the estimation process.

For HSV versus HMV a similar trend is observed. For this reason, weighted linear regression have head to determine the relation between speeds of 3W and HSV and HMV and HSV. Traffic patterns often depend on the time of day, and there are variations between peak hours and off-peak times and nights. To assess those ruling, Batch Interface's full day data was plotted. Figure 3 provides an example graph of the travel time. A 150 second travel time was chosen as a threshold between the dense and non-intensive flow regimes.

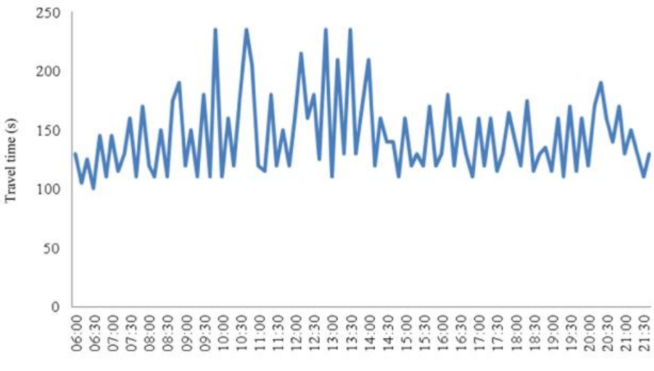

Figure 3 - One-day Traffic Flow Chart

On this basis the congested and normal flow regimes were calculated, and for each of the flow regimes the relationship between HSV and 3W and HMV velocities was formulated separately. In Figure 3 the use of simulated data was extended to achieve adequate sample size. HSV velocity is the average speed of LMV and 2W.

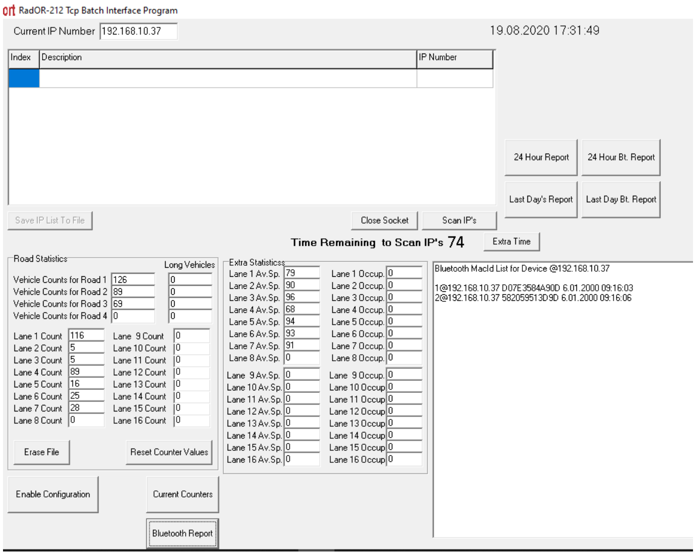

Figure 4 - Bacth Interface Program

An estimation of the linear relationship is made from linear regression between speeds of different groups of vehicles. Using Equation (2) the average flow rate was calculated. Various coefficients used to estimate the average HSV velocity flow rate for different periods of the day, using the observed HSV velocity and projected 3W and HMV velocities, are shown in Table 1.

Table 1. 3W (α_1) and HMV (α_2) Constants at Various Flow Times

Linear constants	**8:^{00}/12:^{00}**	**13:^{30}/16:^{00}**	**15:^{00}/19:^{00}**
α_1	0.84	0.783	0.81
α_2	0.83	0.793	0.83

Validation was performed using simulated data that was obtained on a different day. Classified travel time and speed data for the entire day were created, and HSV speed was calculated by dividing HSV by travel time (average LMV and 2W travel time). The 3W and HMV velocity was determined using the coefficients ranging from α_1 and α_2 obtained as above, and the total flow rate was calculated using the equation (2).

The predicted velocities are in line with the real values of distance. Using the Equation (3) the corresponding flow travel time is measured. For measuring errors, the Mean Absolute Percent Error (MAPE) given in Equation (6) was used.

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{T_e - T_o}{T_o}\right| \times 100 \; ; \qquad (6)$$

T_e and T_o are estimated and observed travel times.

3.2. Discussion

Transport ministries use inductive loops, traffic mobese or probe sensors to predict travel time and monitor travel time. While these conventional systems are verified traffic data collection methods, there are still some disadvantages to each.

Recently, the Floating Car Data, Bluetooth and GPS module systems have given chance more practical method for collecting traffic data and measuring traffic efficiency. Furthermore, all international studies were performed in compliance with European traffic standards which are essentially homogeneous in nature. The basic principles of using Bluetooth for travel time forecasts for heterogeneous traffic conditions remained the same, Turkey has to make major changes to accommodate the way it does.

Turkey is considering the use of GPS technology in future studies to predict travel time under traffic flow conditions. In this case, the two technologies such as Bluetooth and GPS can vary or quite similar. Using GPS and other data sources, companies like Waze, TomTom and Google will have traffic situations at the city and country level after all. Consequently, comparisons should be made across all travel time estimation technologies under various conditions.

4. Conclusions and Recommendations

In this analysis, for potential use as a traffic sensor, the Bluetooth data collected from a busy road on the Ankara Ring Road were analysed. It displays penetration rate analysis, class recognition and flow travel time estimation using Bluetooth.

It was found that the penetration rate was around 5 percent. Most of the vehicles identified are motorcycles and automobiles and deviations have been detected on the data.

Conjecture travel time from restricted Bluetooth data for a whole stream is difficult and so far few work have researched this problem. Data from 2W and LMV were extrapolated in this analysis to approximate travel times for other groups of vehicles, such as three-wheelers and heavy motor vehicles.

For heavy and off-peak traffic flow conditions, actual estimate and analysis of the flow travel time was conducted separately. By weighted linear regression analysis, the study defined linear relationships between the speeds of different vehicle groups, and the approximate flow travel time of the distance divided by the flow velocity was calculated. With an average of 2 per cent MAPE, this technique was effective in accurately estimating flow travel time.

This analysis revealed that Bluetooth is a cost-effective travel time estimation technology for heterogeneous traffic conditions.

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