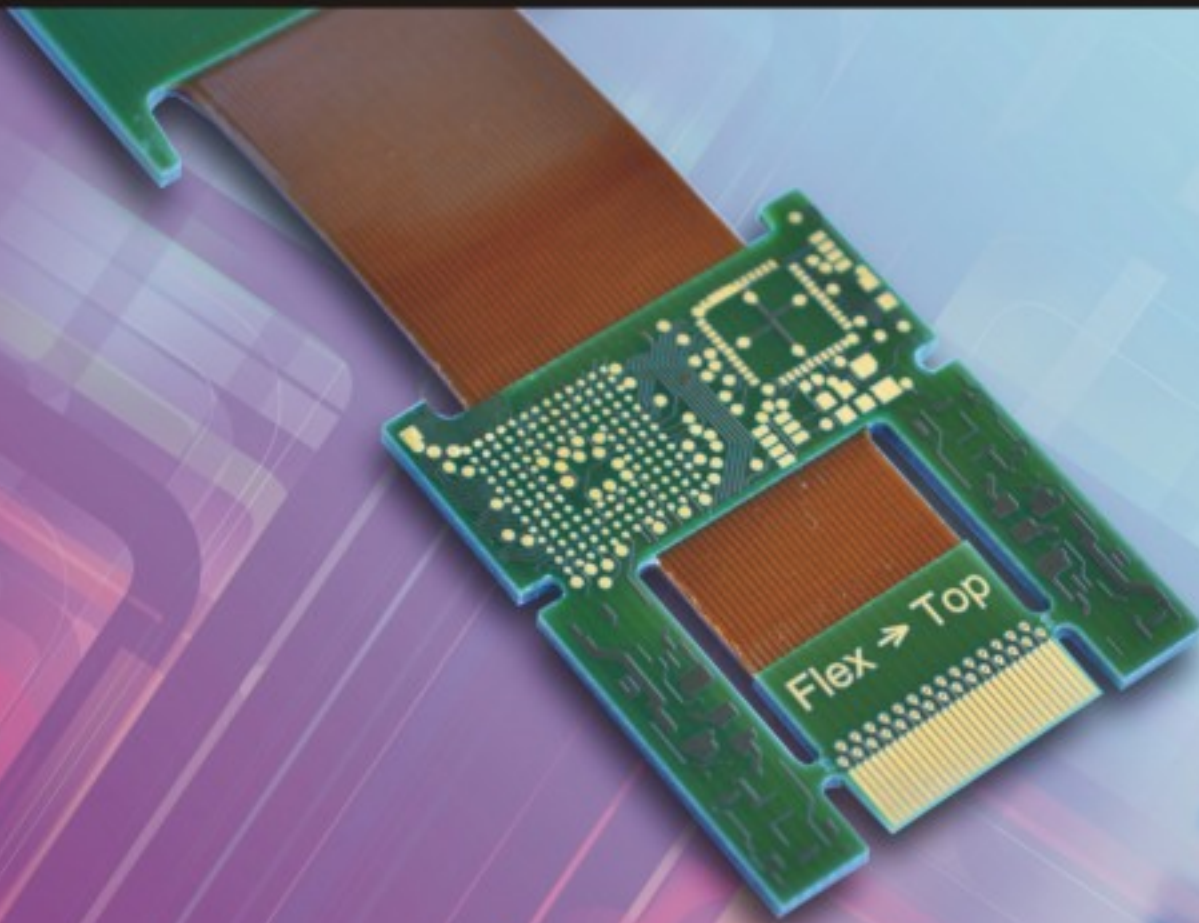


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**Editor-in-Chief**  
Sergey Y. YURISH



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## Digital Sensors and Sensor Systems: Practical Design

**Sergey Y. Yurish**



Formats: printable pdf (Acrobat) and print (hardcover), 419 pages

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e-ISBN: 978-84-615-6957-1

The goal of this book is to help the practitioners achieve the best metrological and technical performances of digital sensors and sensor systems at low cost, and significantly to reduce time-to-market. It should be also useful for students, lectures and professors to provide a solid background of the novel concepts and design approach.

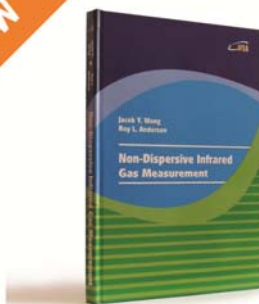
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**Jacob Y. Wong, Roy L. Anderson**

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## A Novel Intelligent Transportation Control Supported by Wireless Sensor Network

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**Abstract:** With the development of wireless sensor unit, and improvement of real-time and quality of wireless communication, the intelligent transportation control system employ these technologies to realize sensing, positioning, computing, and communication for voiding collisions. This paper discusses the framework of transportation control system, and emphasizes TDOA positioning algorithm and the new weighted least square optimization method. The simulation result shows that, our method achieves high-accuracy of positioning, which can satisfy the need of transportation control. Finally, we outline the urgent work need to address in the future. *Copyright © 2013 IFSA.*

**Keywords:** Intelligent transportation control, Wireless positioning, TDOA, Vehicular wireless sensor network, Weighted least square.

---

### 1. Introduction

With the ever increasing production of vehicles and their inevitable role in everyday life, transportation systems are drawing the attention of industry and academia more than any other time. Despite the undeniable beneficial aspects of transportation systems, there are numerous factors by which they impair our everyday life. Without any doubt, many of us have experienced being trapped in heavy traffic, wasting our time and energy resources [1]. While six million car accidents [2] and a combined cost of accidents and congestion totaling \$232 billion [3] are reported annually in the United States, there is a critical role for connecting vehicles wirelessly before the onset of collisions and congestion. More than 57 % of system failures can be

directly or indirectly attributed to human errors such as inattention, lack of cooperation, and poor decisions [4]. Integrating sensing, positioning, computing, and communication components into these physical entities will result in a novel intelligent transportation control system that minimizes human errors and thus revolutionizes system operation.

If a car passes through the crossroad with speed of 40 km per hour, the novel intelligent transportation control should know the location of at first [5, 6]. Then, the researchers will integrate vehicle dynamics and communication with a field theory model to predict vehicle motion for identifying safety hazards and proactive collision warning, and mine traffic data for dynamic vehicle routing [7, 8]. So, the accurate positioning is the basic of transportation control.

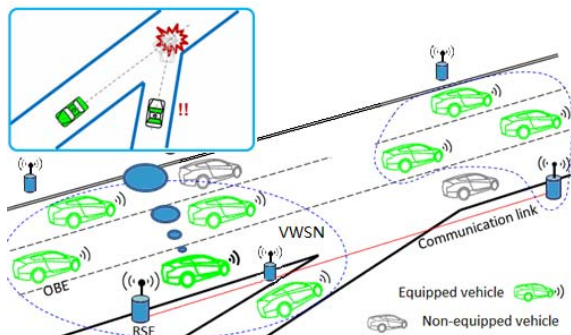
The remainder of this paper is organized as follows: We discuss the related work of



transportation control system in Section 2. In Section 3, we emphasize the high accuracy positioning technology for vehicle. Section 4 outlines the simulation result, and Section 5 concludes this paper.

## 2. Related Work

In the near future, The novel transportation control system envisions that each future vehicle will be equipped with an On-Board Equipment (OBE) which includes a Dedicated Short Range Communications (DSRC) [9] transceiver, a high accuracy positioning system transceiver, a processing unit, and possibly appropriate sensing accessories. Also equipped with similar devices, Road Side Equipment (RSE) will be deployed at selected roadside locations. Therefore, vehicles will be able to communicate with each other and with the roadside by means of wireless sensor network (WSN). Thus, as sketched in the Fig. 1, these components will form vehicular wireless sensor networks (VWSN), within which connected vehicles will be able to “talk” to each other. Envisioned in each OBE is a Co-Driver that will proactively monitor safety hazards in its vicinity and warn the human driver of any imminent collision. Meanwhile, an RSE can retrieve data logged in an OBE when its host vehicle passes by. Through wireless communications, such data are shared with other RSEs. Hence, the RSE is able to maintain a dynamic traffic map of the entire network, which can be queried by the Co-Driver. As such, the Co-Driver is able to advise its human driver optimal routes to avoid collision.



**Fig. 1.** Overview of intelligent transportation control system.

The one of key issues of intelligent transportation control is positioning. The accurate location of vehicle is basic of safety hazard predication. As the low positioning accuracy of Global Positioning System (GPS), we should develop a new wireless positioning technology. The high accuracy positioning technology will discuss in next section in detail.

## 3. Wireless Positioning

Although vehicle passive (e.g. seatbelts and air bags) and active (e.g. adaptive cruise control) systems have been developed to improve safety, a proactive system can complement the above systems to transform vehicle safety by looking forward in time to identify potential safety hazard. Positioning plays an important role in the transportation system. If a control unit of vehicle have ability to track the location of himself and other vehicle around him, such capabilities would greatly improve safety. GPS is the most widely used satellite-based positioning system that offers maximum coverage, but the positioning accuracy of GPS only achieve about 3 m [10], which can not satisfy the need of transportation control. In recent years, wireless sensor networks' low-power organization, heterogeneous interconnect and other key technologies to achieve greater research progress. Ultra Wideband (UWB) is favorable alternative. UWB has good real-time performance, which supports continued up to 160 HZ refresh rate, which means that each sensor or positioning unit to locate the target speed of 6.25 ms. Meanwhile, within a distance of 10 meters , UWB can play up to 500 Mbps transmission performance [11-13]. In VWSN of transportation control system, we use UWB radio as the communication medium to realize the function of positioning.

The positioning algorithms can be categorized according to different criteria. One way of classifying positioning algorithm is on the system computing way. The algorithms can be grouped as centralized computation positioning and distributed computation positioning [5, 14-17]. Centralized computation positioning algorithm is controlled through a central terminal server, which centrally provides the processing, calculating, wireless communicating and storage. Every node has its own process unit for processing, communicating and storage in distributed computation positioning algorithm. There is an advantage of centralized positioning algorithm. It can obtain relatively more accurate location estimation than distribute positioning. Since centralized server owns unlimited calculation ability and storage capacity [16, 18-20]. The centralized positioning algorithm is adopted in transportation control system. Now, we emphasis on discussion of time difference of arrival (TDOA) positioning algorithm in this paper.

The TDOA algorithm can be seen as the intersection of hyperbolas in 2D plane. Positioning systems that use the TDOA algorithm measure the difference in transmission times between signals received from each of the target (mobile vehicle) to RSEs, whose location is known. TDOA requires the RSEs record any received signal. TDOA requires that each signal be transmitted synchronously, either at the same time or with some known delay occurring in signal transmissions.

A 2-D target location can be estimated from the two intersections of two or more TDOA

measurements. Three RSEs ( $N_0$ ,  $N_1$ , and  $N_2$ ) are required, whose location is pre-established.

Each of the RSEs receives a signal synchronously from the target and record when the signal is received. This information is forwarded to a positioning server which calculates the received signal's time difference between each of the anchor nodes. This difference is transformed through an algorithm to provide an estimated location of the target. Mathematically, the target node is located at the intersection of hyperbolas in a 2D plane. The location of a mobile transmitter in a 2D plane can be illustrated in Fig. 2. The equation is given by

$$\begin{aligned} ct_{01} &= \sqrt{(x-x_0)^2 + (y-y_0)^2} \\ &\quad - \sqrt{(x-x_1)^2 + (y-y_1)^2} = D_0 - D_1 \\ ct_{02} &= \sqrt{(x-x_0)^2 + (y-y_0)^2} \\ &\quad - \sqrt{(x-x_2)^2 + (y-y_2)^2} = D_0 - D_2 \end{aligned} \quad (1)$$

where  $(x_0, y_0)$ ,  $(x_1, y_1)$ , and  $(x_2, y_2)$  represent the coordinate of anchor nodes ( $N_0$ ,  $N_1$  and  $N_2$ ) respectively, and  $(x, y)$  represents the mobile transmitter. The  $t_{01}$  represents the difference of time arrive of  $N_0$  and  $N_1$ . According to simultaneous formulas,  $(x, y)$  can be deduced. But only depend on three anchor nodes, the precision of location can not be guaranteed. In order to increase the positioning accuracy, we introduce least square (LS) method into TDOA algorithm [21].

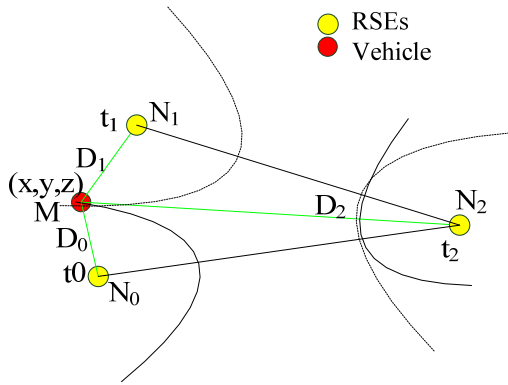


Fig. 2. Positioning based on TDOA algorithm.

Assume the amount of all anchor nodes is  $n$ , for each anchor node  $i$ ,  $i \in [1, n]$ , the distance  $d_{0i}$  relative to anchor node  $N_0$  can be derived from following equation

$$\begin{aligned} d_{0i} &= ct_{0i} = \sqrt{(x-x_0)^2 + (y-y_0)^2} \\ &\quad - \sqrt{(x-x_i)^2 + (y-y_i)^2} = D_0 - D_i, \end{aligned} \quad (2)$$

where

$$\begin{aligned} D_0^2 - D_i^2 &= \|M - N_0\|^2 - \|M - N_i\|^2 \\ &= ((x-x_0)^2 + (y-y_0)^2) \\ &\quad - ((x-x_i)^2 + (y-y_i)^2) \\ &= x_0^2 - x_i^2 + 2x(x_i - x_0) + y_0^2 \\ &\quad - y_i^2 + 2y(y_i - y_0) \\ &= D_0^2 - (D_0 - d_{0i})^2 \\ &= 2D_0d_{0i} - d_{0i}^2 \end{aligned} \quad (3)$$

Group all the known terms together and denote

$$b_i = \frac{1}{2} [x_0^2 - x_i^2 + y_0^2 - y_i^2 + d_{0i}^2] \quad (4)$$

which is a linear model for unknown parameters  $(x, y)$  and  $D_0$ . Stacking the  $n$  nodes measurement, we have the linear system in matrix form

$$AX = b \quad (5)$$

where

$$A = \begin{bmatrix} x_0 - x_1 & y_0 - y_1 & d_{01} \\ x_0 - x_2 & y_0 - y_2 & d_{02} \\ \vdots & \vdots & \vdots \\ x_0 - x_n & y_0 - y_n & d_{0n} \end{bmatrix}$$

$$X = \begin{bmatrix} x \\ y \\ D_0 \end{bmatrix}, \quad b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}$$

When the location of nodes can be precisely known and the TDOA measurements are noise-free, linear system is compatible. The solution is unique while the data matrix  $A$  is of full rank. Let  $e$  represents the error of observation value and ideal value.

$$\begin{aligned} \sum_{i=1}^n e_i^2 &= \sum_{i=1}^n (b_i - b_{1si})^2 \\ \Rightarrow E^T E &= (b - AX)^T (b - AX) \end{aligned} \quad (6)$$

where

$$E = [e_1 \quad e_2 \quad \dots \quad e_n]^T$$

According to least square principle, we conduct the derivative of equation (6). We have

$$\partial(b - AX)^T (b - AX) / \partial X = 0 \quad (7)$$

Once a minimizing  $b_{1s}$  is found, then any  $X$  satisfying  $AX = b_{1s}$  can be called an LS solution

and  $b - b_{ls}$  the corresponding LS correction. The unique LS solution can be obtained while the data matrix A is of full rank:

$$X_{ls} = (A^T A)^{-1} A^T b \quad (8)$$

Finally, the location  $(x, y)$  is deduced.

For better performance, we can add a weighting matrix  $W$  to (7). This leads to the following constrained optimization problem:

$$\partial((b - AX)^T W (b - AX)) / \partial X = 0 \quad (9)$$

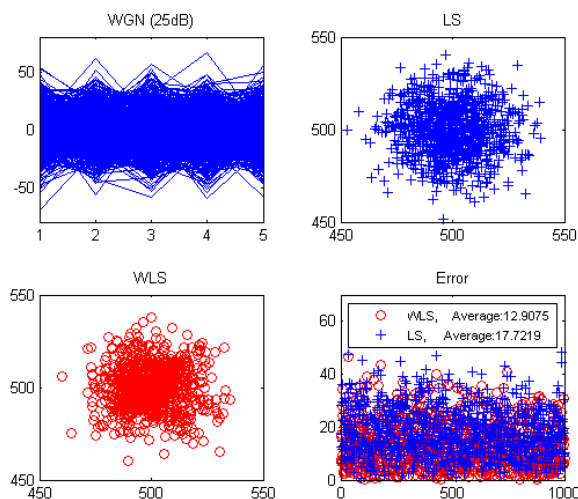
We will obtain matrix representation as formula (10).

$$X_{WLS} = (A^T (W + W^T) A)^{-1} A^T (W + W^T) b \quad (10)$$

#### 4. Simulation Result

Computer simulations had been conducted to evaluate the performance of the proposed TDOA-based positioning algorithms for transportation control. We considered a five-anchor nodes geometry with coordinates  $(0, 0)$  cm,  $(0, 2000)$  cm,  $(2000, 0)$  cm,  $(2000, 2000)$  cm, and  $(1000, 1000)$  cm, and a mobile node  $(500, 500)$  cm. All results were averages of 1000 independent runs.

Fig. 3 top left corner plots the 25 dBW white Gaussian noise (WGN) of the LS, WLS method; top right corner shows the LS estimator; lower left corner illustrates the WLS estimator; lower right corner plots the error of two methods and average error. The simulation result shows the average positioning accuracy of WLS method is 12.9075 cm.

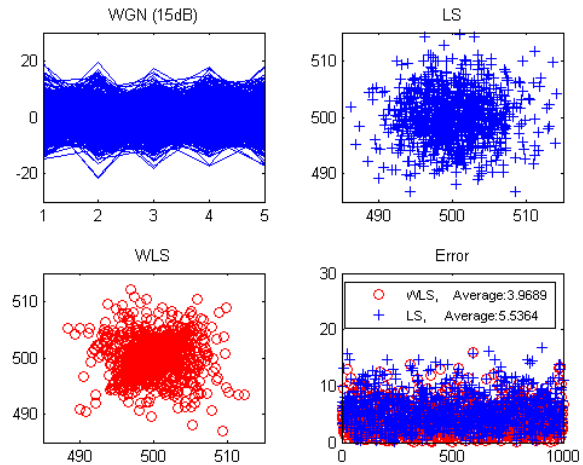


**Fig. 3.** The estimated result of the LS and WLS estimator at  $(x, y) = (500; 500)$  cm under 25 dBW noise.

Meanwhile, we test the LS and WLS method under 15 dBW noise, the average accuracy of WLS

positioning method is 3.9689 cm. The simulation result is shown in Fig. 4.

From the simulation result, the average error of WLS based UWB is less than 15 cm in the 20 m<sup>2</sup> coverage of crossroads under 25 dBW and 4cm under 15 dBW, which can satisfy the requirement of transportation control.



**Fig. 4.** The estimated result of the LS and WLS estimator at  $(x, y) = (500; 500)$  cm under 15 dBW noise.

#### 5. Conclusion

The successful accomplishment of positioning provide an innovative method and paradigm for accurate travel time prediction that is able to best utilize the information generated by both connected vehicles and traditional traffic detectors.

However, there are some issue need to address in near future. Firstly, a dynamic vehicle routing algorithm will be developed that will fundamentally change how the existing in-vehicle navigation systems work. This algorithm will be able to effectively avoid the potentially dynamic all-or-nothing assignment results, and move the network traffic flow towards a state of dynamic system optimal. Secondly, mine traffic data for dynamic vehicle routing. Based on vehicle wireless communication network, we will develop new algorithms to estimate and predict travel time in real time, and combine the result with accident prediction to support dynamic route choice for drivers to avoid congestion. Finally, energy-saving is also a problem need to solve.

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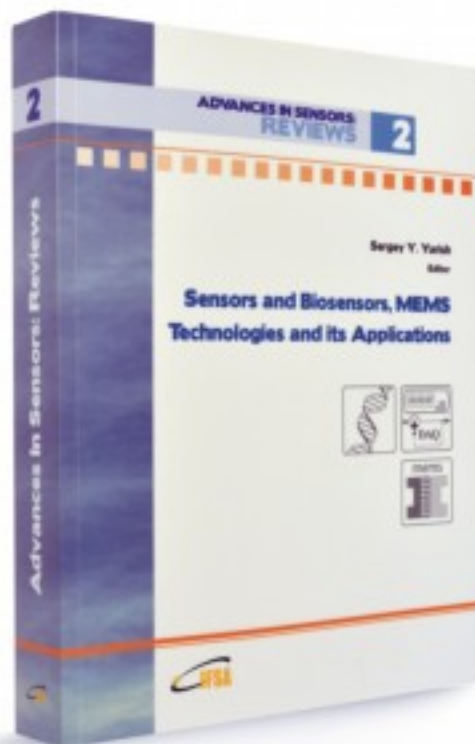
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