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# A survey of ranging techniques for vehicle localization in intelligence transportation system: challenges and opportunities

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**ABSTRACT**

Observing the vehicles movement becomes an urgent necessity due to exponentially increasing numbers of vehicles in the world. However, to this regard, a good deal of research had been presented to estimate the exact physical position of the vehicle. The major challenges faced vehicle localization systems are large coverage areas required, positioning at diverse environments and positioning during a high-speed movement. However, in this paper, the challenges of employing the vehicle localization techniques, which rely on the propagation signal properties, are discussed. Moreover, a comparison between these techniques, in terms of accuracy, responsiveness, scalability, cost, and complexity, is conducted. The presented positioning technologies are classified into five categories: satellite based, radio frequency based, radio waves based, optical based, and sound based. The discussion shows that, both of satellite-based technology and cellular-based technology are emerge solutions to overcome the challenges of vehicle positioning. Satellite-based can provide a high accurate positioning in open outdoor environment, whereas the cellular-based can provide accurate and reliable vehicle localization in urban environment, it can support non-line of sight (NLOS) positioning and provide large coverage and high data transmission. The paper also shows that, the standalone localization technology still has limitations. Therefore, we discussed how the presented techniques are integrated to improve the positioning performance.



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## 1. INTRODUCTION

Due to the dramatically increase of the number of vehicles in the world, which inevitable leads to increase the congestion and accordingly increase the probability of accidents occurring, the observation and control of the vehicles' movement on the road becomes an urgent necessity. The knowledge of vehicles' position information must be sufficiently accurate. To this end, the vehicles' movement parameters including position, speed and orientation must be precisely determined. This operation is called vehicles localization or vehicles positioning. In general, the localization is a wide concept aims to determine the location of the objects that are located in diverse environments. The objects maybe mobile phones [1], [2], cart's location at malls [3], patient at hospital [4], employees in the building [5] or vehicles in the road [6]. The environment is either indoor, outdoor, or mixed. The vehicles positioning technologies in some research are classified depending on the nature of the vehicular ad hoc networks (VANET) [7], [8] whereas other research classified the vehicles localization depending on type of the sensor to on board and off board technology [9]. Also, some research classified the vehicles localization technologies depending on the type of target environment (indoor and outdoor) [10]. However, the geomatric based positioning techniques are become the most promising in recent era [11]. Motivated by this it has been selected to be the research gap to be reviewed in this research. Geometricaly, the positioning process is accomplished in a sequential manner through two stages. The distance between the references to the target to be located is firstly calculated by using signal properties ((time of arrival (TOA), time difference of arrival (TDOA), and received signal strength (RSS)). Then, based on localization algorithms, usually using angle of arrived (AOA) and angle of departure (AOD), the relative position is concluded. However, the localization systems are generally evaluated by accuracy. However, regard to the vehicle positioning systems, there are additional criteria must be considered such as: responsiveness (how quickly the vehicle position is estimated), adaptiveness (how the vehicle localization system is able to cope the environmental influence changes), scalability (how well the system performs under large number of vehicles location requests), cost, and complexity. However, there are many surveys on vehicles positioning have been proposed in the literature.

This paper aims to present a survey of the state of art of the current vehicle localization systems which rely on the signal properties. The presented vehicle localization systems are further investigated and evaluated according to the previously mentioned criteria. The contribution of this survey is that the presented vehicle localization systems are classified based on the signal properties that used as an intermediary between the reference and the vehicle to be located. Furthermore, this survey is mainly focuse on the challenges and opportunities of employing these techniques on vehicle positioning. The vehicles localization systems, in this paper, are classified to five categories: satellite based, radio frequency (RF) based, radio waves based (RADAR), optical based (LiDAR), and sound based.

The article organization is as follows: after this introduction, the ranging techniques are explained with details in section 2. Section 3 is dedicated for vehicles localization algorithms. Furthermore, the challenges of localization algorithms in vehicle positioning are presented. Then, an overview of the positioning technologies based on signal properties and potential to apply this technique in vehicle localization aspect are presented in section 4. The integrative of vehicle technologies is conducted in section 5. Finally, the conclusions are drowned in section 6.

## 2. RANGING TECHNIQUES BASED ON SIGNAL PROPERTIES

Ranging technique is defined as the methods of calculating the separated distance between two connected points based on the parameters of the propagated wireless signal. It considered the basic stage of the geomitrcaly based positioning techniques as mentioned above. TOA and RSS are the most popular parameters that can be translated into distance. While the angular parameters, (i.e., AOA and AOD) are usually joined to improve the ranging accuracy. However, the following subsections are dedicated for explaining the ranging methods.

### 2.1. Distance based ranging

The distance based ranging techniques translate the recorded signal properties into distances which can be perfectly used for computing the real distance to the receiver [12]. However, the distance measurement can be established based on two prevalent known properties, they are: received signal strength, RSS, time of arrival, and TOA [13]. However, since this work is directed to focus on vehicle positioning; therefore, the state of the art in this section focusses on employment the signal properties for vehicles ranging estimation.

#### 2.1.1. Received signal strength-based ranging

As is known that the signal suffers from attenuation as it propagates farther from the transmission point. In other words, it is possible to conclude the propagation distance from the known path loss or power level of transmitted signal. The distance between two wirelessly connected points can be extracted from the (1):

$$RSS = RSS_0 - 10\gamma log(d/d_0) + n \quad (1)$$

where, RSS is the received signal strength in dB, RSS0 is the received signal strength, also in dB, at the reference distance $d_0$ (usually considere $d_0$=1 m), γ is represent how the power is attenuate over the distance $d$. The main advantage of RSS based ranging is that there is no synchronization between the two connected points is required. RSS based ranging can perfectly applied in short rangs, it famously implemented using one of two localization methods, namely trilateration or signal fingerprint method [13], [14]. However, the main drawback of RSS is that the received power may affected by multipath and shadow [15]. Therefore, with respect to vehicles positioning, RSS ranging technique is not more suitable because impossibility to keep line of sight path and requires the large coverage area. However, some previous works had been proposed to solve RSS limitations, for example in [16], [17], two-way ground reflection and log-distance shadowing are utilized to mitigate the effects of interference and signal attenuation.

#### 2.1.2. Time of arrived based ranging

In this technique, the requred time to propagate the signal from the source to the distinction is converted to distance based on the relation $d=t\times c$, where $c$ is light speed [18]. For localization purpose, TOA technique have been proposed in some pervious works [19], [20]. Hu *et al.* [20] developed a new method of vehicle positioning based on ultra-wide band (UWB) technique using TOA and below 10 cm ranging error was achieved. However, to improve the TOA ranging accuracy, real time synchronization between both source and distination is required [21]. This leads to increase the costs and hardware complexity. However, to overcome the synchronization problem, TDOA is implemented as in [22], [23]. In addition, TDOA can increase the accuracy receiver positioning [24]. However, both TOA and TDOA techniques have been presented in many localization systems. For example, vehicle positioning system based on the TOA have been conducted in [25]. Moreover, Fokin [26] developed a three-stage TDOA algorithm for positioning a transmitter in non-line of sight (NLOS) conditions when there are up to two receivers with NLOS measurements. However, the main drawback of TDOA is that more complex calculations are required.

### 2.2. Direction based ranging

This technicque is basically applied with the previous techniques. In this technique the direct distance between two communicated points is calculated by knowing the AOA or AOD. Then, the position can be then estimated by using triangle relationships [18]. However, in direction techniques, array antennas or highly directional antennas are used to extract the direction information, and to get more precisely AOA information, the number of the antenna arrays should be increased [27]. This leads to increase the cost and complexity of AOA implementation. Another drawback is direction of arrival (DOA) affected by the nonline of sight signal propagation and multipath reflections in the urban environment. However, DOA technique for localization application in both 2-D and 3-D have been widely introduced and studied in some previous works [28]–[31]. In [32], a joint of AOD and RSS method have been used to estimate the user location. The proposed method showed that, the localization error of this method had been significantly reduced compared to use AOD or RSS standalone. Similarly, in the study [33] the authors exploit multipath transmissions information (AOA, AOD and TOA) to detect the hidden vehicle. Although the proposed approach provided satisfied results for petitioning the hidden vehicle, but the designed approach suffered from complexity and too many calculations are required.

In brief, the signal properties are very important elements that can be used for determining the vehicles position. However, it is important to mention that, both the signal property and the positioning techniques should be applied together to estimate the exact position of vehicles. Therefore, positioning algorithms are very important to be understanding. Hence, we dedicated the following section for explaining the positioning techniques.

## 3. VEHICLE POSITIONING TECHNIQUES

Currently, various vehicles localization techniques had been proposed in the literature [9]. They can be generally classified based on type of the incoming signal properties into two general categories: geometrical and statistical techniques, as shown in Figure 1. In the geometrical localization approach, the measurements of the incoming signal properties (TOA or RSS) are exploited to establish the propagation distance between the unknown vehicle to the reference (base station or to another known vehicle), then by using AOA and based on the geometric relationships euclidean distance and the relative position of the unknown vehicle is identified. While in the statistical estimation approach, the measured properties of the incoming signal, which is usually the RSS, is treated as the random variable However, positioning techniques are succinctly explained in the following.

### 3.1. Geomitrical localization techniques

#### 3.1.1. Triangulation technique

In triangulation technique, the positioning process is established based on the triangle's geometric properties. the computed angular with the measured distance to the relative reference point are exploited to estimate the position of the target [34], [35]. The distance between the reference, which is usually fixed point, to the target to be located is calculated by using AOA technique [36]. The position of the target can be efficiently estimated based on the known position of the references and the calculated distance to the target [37]. However, the number of reference points in some researches are reduced to decrease the cost of the system.

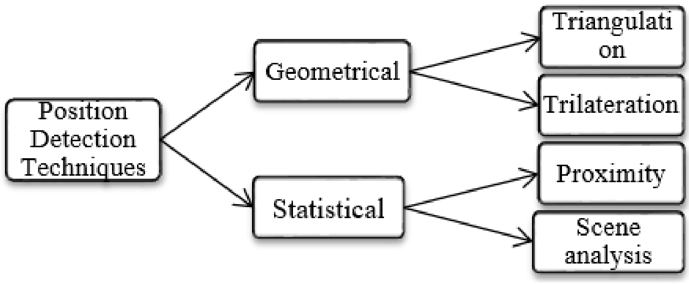


Figure 1. Position detection techniques classification

#### 3.1.2. Trilateration technique

Trilateration technique, also sometimes called lateration, uses the geometric properties of the triangle. The position of the target is determined by computing attention of the transmitted signal based on the measured distance to at minimum three reference [38]. The distances between the references and the point to be located in trilateration technique are calculated by using TOA, TDOA or RSS [39].

#### 3.1.3. Challenges of geometrical techniques in vehicle localization

Usually in the vehicle localization applications, wider coverage area with multiple reference points is required to achieve a higher level of accuracy. Which leads to increase the cost and infrastructure hardware. Moreover, the geometrical algorithms are dependent on either AOA or TDOA to calculate the reference to the target; however, the divers of environmental conditions of vehicles applications may introduce some errors in AOA and TDOA measurements, which affects to the localization accuracy. Another major challenge is the vehicle position determination may contain errors due to the high navigation speed.

### 3.2. Statical localization techniques

#### 3.2.1. Proximity technique

In this technique, the object's position is determined based on estimated distance to the located transmeters at previous known positions. The exact position of the object, in this technique, is not absolutely determined. Only the position information are provided, and the position of the object is approximated by the closest antenna [40]. This technique has been widely used in indoor localization scenarios due to the short range of the separation distance between the transmitters (e.g., access points). This technique has low complexity, but the accuracy of this technique is qute limited [41].

#### 3.2.2. Scene analysis technique

Scene analysis technique, also called fingerprint method, is established in two stages: offline phase and real time phase, as explained in the following [42]. In the first stage offline phase, which also called training phase, the radio maps are formed by measuring the signal strength at fixed points from the base stations within the coverage area to create reference points. These reference points are set as a grid to cover the interested region [43]. In the second stage real time phase, which also named measurement phase, the RSS indication is first recorded by the tracked object, then a matching process is carried out with the recorded offline databases to conclude the objective position [44].

#### 3.2.3. Challenges of statical techniques in vehicle localization

Finding the exact position of the vehicles and providing a higher level of localization accuracy is very important task in some vehicle applications such as autonomous vehicles driving. However, since in the proximity technique, the exact position cannot be absolutely estimated, and only the position information is provided. This leads to the ability to use the proximity technique in vehicle localization applications is very limited as the literature showed. Regarding another statical technique, which is scene analysis, it can present a thigh localization accuracy provided that the offline databases are periodically updated and in short time. In addition, the number of reference points should be increased to cover large area.

## 4. POSITIONING TECHNOLOGIES FROM VEHICLE PERSPECTIVE

Estimating the position of the vehicle is the most important operation in vehicle positioning systems. With Knowledge of vehicle position, the control of vehicles' movement reduces the congestion in addition accidents avoidance. Up to date the researchers have attempted to estimate the vehicles positions with varied methods. They proposed several localization technologies to extract the position of the vehicles. However, in this part, an overview of positioning technologies, which are based on the geometrical concept are presented and the potential to apply these technologies for vehicle localization is addressed. Furthermore, the challenges and drawbacks are discussed; as well as a comparison between these technologies is provided in terms of accuracy, cost and their characteristics and limitations, and finly this comparison is summarized in Table 1, at the end of this section. The presented technolegies are classified to five categories based on the type of the transmission signal. These categories are satellite-based technology, RF based technology, RADAR, LiDAR, and sound-based technology.

Table 1. Summary and comparison of vehicle positioning technologies

| Technology | Category | Technique | Algorithm | Advantages | Drawbacks and challenges |
|---|---|---|---|---|---|
| Satellite Based | GPS | TOA, TDOA | Trilateration | Low cost. Provide a good accuracy at open areas. Low complexity. | low accuracy at urban city. Cannot be used at very high velocity. |
| Radio Frequency Based | Bluetooth | RSS, TDOA | Fingerprinting, Trilateration | Low cost. Low power. Small size. | Short range (10 m). |
| | UWB | TOA, TDOA | Trilateration | High accuracy. | Range up to 75 m. More UWB sensors required for wide coverage area. |
| | WiFi | RSS, TDOA | Fingerprinting, Trilateration | Medium range (100 to 300 m (WAVE)). | Hand over issue due to cross several network cells when vehicle travels with high speed. |
| | Cellular | RSS, TOA, AOA | Fingerprinting, Trilateration, Triangulation | Wide coverage area. Greater availability in urban areas. Suitable for high speed. Support NLOS. | Less precise compared to GPS. The accuracy depends on the environment condition and number of base stations. |
| Radio waves Based | Radar | TOA, TDOA | Trilateration | More robust, not affected by the weather. | Short range (Maximum range 200 m). More sensors are required to cover wide area. |
| Sound Based | Ultrasonic | TOA, TDOA, AOA | Trilateration, Triangulation | Low cost. Unaffected by weather conditions. | Short rang (2m), LOS required, Suitable only for low speed. |
| Optical Based | LiDAR | TDOA, AOA | Trilateration, Triangulation | Light sensors cover wide area | LOS required. Suffer from environmental conditions. High cost. |

### 4.1. Satellite based technology

Global navigation satellite system (GNSS) is general term refers to any satellite constellation that offers services such as positioning and navigation on a global area. Presently, there are several GNSS have been developed in the world. The global position system (GPS) is the most common of GNSSs that have been used for vehicles position detection, so, the state of art will be described in the following section. Readers refer to [45] for more details for other GNSSs.

#### 4.1.1. Global position system

GPS, till now, is considered the most prevalent GNSS that have been used to navigate and locate the devices such as vehicles and mobile nodes. GPS uses a collection of 24 satellites that operate in orbit around the earth. This technique relies on four satellites to monitor each region of the world. It provides relatively high accuracy with error ranges form few meters to 20 meters [46], [47]. Only three satellites must be avaliable to estimate the vehicle’s position. By using the equipped GPS receivers on the device, the vehicle can estimate the distances to the three satellites based on TOA and conclude its position [7]. GPS provides accurate location information of the vehicles if GPS signal is not exposed to impediments. In other words, this technology is inefficient for all situations (urban environment, hostel weather) due to multiple signal reflections. GPS accuracy can be ameliorated upon by using some solutions such as differential GPS (DGPS), assisted GPS (AGPS) [48]. Despite the provided advantages of this technique, such as low cost and high accuracy, it works with some limitations, for instance GPS accuracy affected by the multiple signal reflections in urban environments.

### 4.2. Radio frequency-based technology

In these technologies, the devices are connected to one another through wireless networks by using radio communication. The transmitted signals properties are used to conclude the distance to the transmitter. However, these technologies have the advantages, such as ability to to penetrate walls and obstacles as well as reusing existing RF infrastructures which leading to provide a wider coverage area and reduce the cost. However, based on the ranging, wireless networks are further classified to Bluetooth, UWB, wireless fidelity (WiFi) and cellular (i.e., 3GPP, LTE, 5G). Brief explanations of these technologies are provided in this section.

#### 4.2.1. Bluetooth based technology

Bluetooth is short range wireless network technology utilized for data exchange. It is one type of personal area network (PAN). Up to 1 to 4 Mbps data rate can be provided with variable coverage ranges [49]. Bluetooth technique can be used to locate and track objects e.g., mobile phones, vehicles and so on. Due to short range of this technique, it is limited to use for inter-vehicle communication [50], but it is widely used for indoor localization [51], for instance used for computing of smart phone position [52]. Despite of the provided short range in this technique, it is also have applied to vehicle localization to achieve higher positioning precision by integrating with another techniques, as developed in [53], they exploit its advantages such as low power, low cost and high accuracy. Bluetooth technology also can be used as an integral part of intelligent transportation systems (ITS) to measure of traffic presence, density, and flow as presented in [54]. Yuan *et al.* [55] developed a vehicle localization approach, namely, the line output converter (LOC) in-a-car, based on functional exploration and full use of multi-channel received signal strength indicator of Bluetooth low energy to overcome the effects of the reflected signals, which is considered the significant challenge and significantly affected to the positioning accuracy.

#### 4.2.2. Ultra wide band-based technology

UWB is a wireless technology that provides a high speed data transmission over a wide portion of the frequency spectrum (more than several hundred megahertz), and usually it used for short rang [56], [57]. UWB offered some characteristics such as capability tp penetrate the obstacles due to using the large wavelengths of the radio signals. Therefore, it can provide a high level of positioning accuracy in addition reduce interference and multipath issues. However, UWB can provide superior accuracy to measure the distance by utilizing TOA or AOA in some applications to provide more precisely position detection [58]. However, despite presence of these characteristic, UWB has been limited used for outdoor applications due to the provided short range (maximum 200 meters). Therefore, this technology is limited in use for vehicle localization. Che *et al.* [59] used machine learning to improve the positioning accuracy based ranging estimates, the measured distance error was mitigated to less than 10 cm. However, in dense environments, UWB can be applied as a robust solution for assist localization with NLOS and can easily penetrate in the obstacles [60]. Over the communications between different UWB stations, its sensor concludes the vehicle relative position to a fixed station. In other words, a well-developed infrastructure is required due to the short range of the signals. However, [20] proposed a vehicle positioning method based on UWB, they used improved TOA approach for vehicle position detection. The achieved result of this technique has higher accuracy compared to the traditional GPS.

#### 4.2.3. Wireless fidelity-based technology

Another technology employed in radio waves positioning systems is Wi-Fi. The data transmission rates of Wi-Fi between 6 to 54 Mbps, at communication distance up to 100 m with 100 mW [61]. However, a modified version of WiFi technology (IEEE 802.11p), called dedicated short-range communication (DSRC) or wireless access in vehicular environment (WAVE), is standard specifically proposed for V2V and V2I communication [62]. According to European Commission, Wi-Fi devises that work with 75 MHz of spectrum in the 5.9 GHz band is reserved for vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. In other words, these devices can be utilized for vehicle position detection systems to receive and transmit the information from/to other vehicles as well as infrastructure. However, regarding the cost of the infrastructure and user devices of WiFi is very low. In addition, WiFi range can be increased to several Km. Compared to UWB, Wi-Fi's accuracy is far lesser, because it typically concludes location by using RSS fingerprinting approach ,same as Bluetooth technology, not by distance [63], [64]. Therefore, it can be restricted in advanced vehicles positioning based scenarios. However, Several research have been proposed to localize vehicles through Wi-Fi network [65]. As solution to improve Wi-Fi's localization accuracy, the number of anchors should be increasing, this leads to boost up the cost. To overcome this problem, [66] proposed low cost positioning method based on fingerprint WiFi. The accuracy of vehicles positioning of this method had been improved by using support vector regression increasing without increasing the number of anchors.

#### 4.2.4. Cellular based technology

This technique is considered as a part of vehicle to everything communication (V2X) technology. Through the cellular network, the vehicles communicate with their environments include the vehicles (V2V) and infrastructure (V2I). Different technologies are used in cellular networks such as 3GPP release 14 (long term evolution (LTE)), 3GPP release 15, five generation (5G) and milimeter mwave, to transfer data between the cellular devices [9], [67]. In cellular based technology, there are two modes are offered for vehicular communication, Mode-3 and Mode-4. Mode-3 depends on centralization, the vehicles communicate through the base station while Mode-4 depends on decentralization, where the vehicles are enabled to communicate directly with each other [68]. In addition, different interfaces are used for each mode, Mode-4 uses the PC5 interface at 5.9 GHz while Mode-3 uses the traditional LTE interface [69]. The desired modes may switched dynamically depending on the suitable condition [70]. However, compared to the previous mentioned wireless technologies, cellular based technology offers multiple benefits [71], [72], such as highly reliability and scalability due to the provided bandwidth; therefore, it resolves the problem faced by WiFi technology. Furthermore, the achieved data transmission in cellular based technology is higher compared to the listed previous technologies. Finally, the localization based on cellular technology supports NLOS condition. In the other hand, there are severe security vulnerabilities have been detected in LTE and LTE-A technologies [73], nevertheless the security threats have been handled as introduced in [28]. However, due to these provided characteristics of cellular technology, it widely used in vehicles positioning in the last decade. The position of the vehicle, in this technology, is estimated based on the known base stations of cellular system and the transmitted signal is used to conclude the distance. The distance between BS to the vehicle is usually calculated based on RSS or propagation time [74]. The vehicle positioning can be established by using either the distance to three stations [75] or by the multi paths form single base station [76]–[78]. Due to the high operating frequency of mm-wave, (30 to 300) Gz, this allows to install a large number of antennas at the BSs, which increase the precision of AoA and AOD estimation [79], [80]. In the other meaning, giving opportunity to use it in vehicle positioning.

### 4.3. Radio waves-based technology

Radio wave-based technology, also called radio detection and ranging (RADAR) utilizes the calculated TOA of the echoed signal of the emitting periodic radio waves to measure the distance to the target. It operates in several types of radio waves such as millimeter (mm) wave which is typically utilized in civil and military applications for example at airports [81]. In recent years, the employment of the Radars' transmitters attracts more attention of the researchers. Different radars' transmitters had been proposed. However, based on the transmitter-receiver topology, RADARs is classified to monostatic radar (the transmitter and the receiver are spatially combined) and bistatic radar (the transmitter and the receiver are separated by a distance) [31]. However, in autonomous vehicles, RADARs are extensively employed for scanning the surrounding vehicles environment and detecting the relative position of the vehicle. At present, several frequency bands, e.g., 24 GHz, 60 GHz, 77 GHz and 79 GHz, have been used in modern vehicles to measure a distance from 5 to 200 meters [82]. In RADAR based technology, autonomous vehicles are usually equipped with arrays micro antennas that provide a group of lobes to detect multiple targets and improve the position detection resolution as well [29]. mm-wave RADAR's technology is appropriate for autonomous vehicles applications such as position detection because it can provide a higher penetrability and a wider bandwidth. In addition, mm-wave RADARs can precisely measure the short-range targets in any direction utilizing the variation in doppler shift [83].

### 4.4. Sound based technology

In this technology, the targets position is detected based on the sound waves by using a low-cost sensor. It can be categorized to ultrasonic and acoustic-based. The distance to targets, in both categories, can be concluded by using TOA of the reflected signal [84]. Acoustic-based technology cannot be applied for vehicle position detection, since it utilized the installed microphone and there are many sounds can be captured in outdoor environments. The second category will be explained in the following section.

#### 4.4.1. Ultrasonic technology

Ultrasonic sensors are used to scan the surround environment. It operates with ultrasonic waves from 20 to 40 KHz [85]. However, in this technology, the mechanical waves which can spread through the air or materials are utilized. TOA of the emitted waves is usulay used calculate distance to the target. However, ultrasonic sensors operate at LOS condition with very short rang (generally around 3 m), provides a very narrow beam detection rang and its output updated periodically after every 20 ms [84]. These characteristics make ultrasonic sensors imperfect to use for a moving vehicles position detection. For example, multiple ultrasonic sensors are required to identify the vehicles' size due to the very narrow beam of the ultrasonic sensors [86]. However, ultrasonic sensors had been effectively applied for some warning automotive systems such as auto parking and detect blind spot [87], [88], vehicle's nearby conditions identifying [89], [90] and vehicle's location sensing in relation to devices and pedestrians [91].

### 4.5. Optical based technology

Some areas, such as hospitals, are very sensitive to use radio waves in their surroundings. Therefore, it is necessary to resorting to the use of other vehicles localization technologies that do not depend on radio waves [92]. However, optical communication technology (e.g., visible light communication) can be perfectly used for line-of-sight (LOS) vehicles petitioning [93]. The range to the target, in this technology is calculated based on the TOA of the reflected light at the receiver. It has been shown that it provides a higher positioning accuracy compared to other vehicles positioning technology, for example Wi Fi technology [94]. Furthermore, it can provide a wide light beam which can use for detecting a wide area compared to ultrasonic sensors [95]. In the other hand, the optical based technology (e.g., LiDAR) provides limitations, very high cost and its performance affects by the weather conditions [96], in addition the capability of operating rang detection rely on object reflectiveness [97]. However, the position detection using optical signals can be performed with two technologies called infrared (IR) technology and visible light technology light detection and ranging (LiDAR). IR technology provides some advantages like uncompleted, small size system, and immunity interface, but it affected by light [98]. In addition, the working range of IR is very short, several meters [99]. Thus, IR technology is limited to use for vehicle positioning.

#### 4.5.1. Lidar technology

Generally, LiDAR is widely employed in LOS vehicles localization. It utilizes the 905 nm and 1,550 nm spectra [100]. LiDAR provides maximum working range up to 200 m [93]. Due to capability to provide wide light beam, the collected data by using LiDAR technology is significantly more than the collected data by using Radar sensors and hence a higher positioning accuracy can potentially offer. However, three categories of LiDAR are presented in [101], they are 2D, D and solid-state LiDAR. 2D and 3D use a single laser and multiple laser beam, respectively. In 2D LiDAR, the diffused single laser beam over high speed rotated mirror is utilized while, in 3D LiDAR, the located multiple laser beams on the pod are utilized for obtaining three dimensions image of the surrounding area. Currently, 3D sensors are playing a very important significant role in the autonomous vehicles systems [102]. In solid-state LiDAR, the laser beam is synchronized by utilizing micro-electromechanical system (MEMS) circuit with micro-mirrors to scan the horizontal field-of-view several times. However, recently the LiDARs have been strongly employed for automonus vehicle (AV) applications such as 2D and 3D maps drawing and body identification. As presented in [103], the authors developed 16- line LiDAR system for vehicle localization. The achieved accuracy was 95% within distance around 30 m. A 64-line 3D LiDAR is proposed in [104], and to further improve the pedestrian detection, the author have used support vector machine (SVM)-based algorithm.

## 5. INTEGRATIVE OF VEHICLE LOCALIZATION TECHNOLOGIES

The integrative of localization technologies is a combination of two or more localization technologies. The main goal of integrative positioning technologies is to overcome the presented limitations of using localization technology standalone. As mentioned before, the discussed localization technologies are inaccurate in some situations, the performance of them is strongly affected by variation of the environmental conditions. Naturally, the vehicles are inevitably found in various environments, means that, using one technology cannot achieve the desired accuracy. Therefore, numerous research has been carried out by integrating the petitioning technologies. Among them is the studies in [95]–[97]. Fujii *et al.* [105] combined the onboard sensors to improve GPS accuracy. Furthermore, a novel estimation algorithm which integrates the inertial sensors, measurements of distance sensors and neighboring vehicles' information is proposed in [106], [107]. An accuracy levels, under 1.5 m, is achieved in [108] by developing cooperative positioning system which uses V2V and V2I communications. By the same purpose of improving localization accuracy, the crude GNSS measurements of a group of connected vehicles are matched to digital map [109].

## 6. CONCLUSION

The main goal of vehicle localization system is to monitor and control the vehicles movement to reduce the road congestion and accidents. In this paper, a survey on the vehicle localization technologies, which rely on the signal properties (RSS, AOA, and TOA) has been done considering some evaluation criteria such as accuracy, coverage area, complexity, and cost. The survey has compared five categories of localization technologies. Furthermore, the challenges on the vehicle localization systems have been addressed. We further discussed how localization accuracy is affected by the vehicle speed and coverage area. From the discussion we find that, the vehicle localization systems require spatial specification to against the vehicles movement conditions. However, the survey showed that, satellite satellite-based and cellular-based technologies are the best for vehicle localization. Both of them provide large coverage areas and low cost. With respect to the localization accuracy, satellite-based technology is more suitable for open areas, while cellular-based technology is more suitable for urban environments. The speed is still a major challenge to all reviewed localization systems, this due to the impact of measurement errors on signal properties estimation during high speed. Finally, the survey presented some pervious works that combine two or more localization technologies for the purpose overcome the drawbacks of use each localization technology standalone.

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