Overview and Perspective of Localization Accuracy for Persistent Autonomous Vehicle Systems

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***Abstract*—Autonomous vehicle system in urban scenarios requires precise localization. The GPS-based localization approach in its best form even not able to reach the required level of precision due to the attenuation and multipath of the signals in urban scenarios. Cooperative communication and sensor techniques of the on board units of the vehicles promised to show advantages on localization for its applicability in autonomous vehicle systems. This paper presents an overview of localization techniques and their accuracy ranges for the applicability in autonomous vehicle systems. Environmental changes and its impact on localization accuracy is analyzed for V2V and V2I platforms. Further it has been shown that combining cooperative communication and onboard sensor reading of the vehicle produce better localization accuracy for urban vehicular infrastructure. However, the performance depends upon quality of communication and sensing techniques.**

***Index Terms*—Internet of Things(IoT), Internet of Vehicle(IoV), Sensor Fusion, Vehicular Ad Hoc Network, Global Positioning System(GPS)**

I. Introduction

The huge increment of road vehicle creates issues of pollution, traffic congestion and accidents. To overcome some of these issues autonomous vehicle system is considered as a promising solution facilitating vehicle control and driving. The autonomous driving system is achieved with localization, planning,perception, control and management of the system [1]. The geographic position of the vehicle is obtained by the localization system [2]. The perception system analyses the sensed data from sensor of the neighbouring vehicles. The conditions are traffic signal, obstacle and other road user. The planning system structures the trajectory, speed and braking. It uses the localization and perception system data. Control system regulates the vehicle movement. It takes input from the planning system and generating control signals to steering, break and accelerator. All the operations are monitored by system management. Planning, control and perception system require location from localization system to proper function of the autonomous operation. A decimetre grade error from localization system can be vulnerable and result in severe accidents. The localization system must be robust in uncertain weather and driving conditions like fog, dark, obscured road marking, etc. The global positioning system(GPS) provide a solution for localization. Though it is cheap it has low accuracy($\sim 10m$), multipath and signal blockage issues. For autonomous vehicle system there is a requirement of accurate and robust localization system. There are two solution present in the literature: First is the development of advanced sensors (LiDAR, camera or RADAR etc.), Second fusing sensor data with network infrastructure.

The accurate localization is possible with modern high-end sensors. But these methods with advanced sensor has many drawbacks of high cost, limitation of the line of sight, lacks robustness in environmental conditions like snow or dark. All the above-mentioned drawbacks add up to lowering the localization system performance. The growth of Internet of Things(IoT) [3] opens a way for accessing various vehicle information like weather, nearby vehicle, traffic information for location estimation [2]. The vehicles connected to form inter-vehicle, intra-vehicle or mobile vehicular network to form Internet of Vehicles(IoV) [4], [5]. Wireless connectivity embedded in vehicular system forms V2X system where X=V=Vehicle in V2V(vehicle-to-vehicle), X=I=Infrastructure in V2I(vehicle-to-infrastructure), X=S=Sensor in V2S(vehicle-to-sensor) etc. [6]. These modern technology can be blended with localization system to enhance localization accuracy and robustness to tackle the line-of-sight problems. There are various research work present in the literature for localization uses advanced sensors technology, sensor deployment [7] , fingerprint mapping [8] and data fusion methods but still lack in deployment in autonomous vehicle in realistic scenarios.

In this paper, a new approach is presented based upon data fusion model for localization. The remaining paper is organised as follows. Section II presents related work for recent localization methods. Section III represent system model followed by localization algorithm in section IV. In section V analysis is presented followed by conclusion.

II. Related Work

Embedding modern communication systems in vehicular system to form V2V and V2I have the potential to increase localization accuracy, reliability, and robustness in IoV systems [9]. These systems comprising vehicles embedded with broadcasting sensor which broadcast speed, location, heading, and weather. These broadcasted information collected by a vehicle and cooperatively localize itself. There are several approaches of localization using these broadcasting signals

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like time of arrival(ToA), the time difference of arrival(TDoA), angle of arrival(AoA), received signal strength(RSS) [2] [10]. In ToA method the vehicle transmit signal to the RSU which reply signal back to vehicle.From the difference in the time interval the relative location of the vehicle is estimated. This method is limited since all the nodes should be time synchronised for accurate estimation. This synchronization problem is overcome by the time difference of arrival(TDoA) method [11]. The angle of arrival(AoA) method uses antenna arrays to measure relative angles of the neighbour vehicle to estimate the location. However the antenna array for each node increase the cost of deployment. Receiver signal strength(RSS) method measure the signal attenuation from the near by vehicle and estimate the location. This method need none extra hardware but limited to fading and multipath effects. Using UWB sensors to estimate the vehicle location requires standardise infrastructure since the UWB signals are short range so it is only applicable in industrial autonomous vehicles [12]. Radio wave based vehicular localization system are based on the cellular network or WiFi. These systems operate in 5.9GHz band which is reserved for V2V and V2I communication [13]. These systems are infrastructure based made up of access-point or infrastructure less. Cellular network based vehicular localization system use base station and ranging method for localization.

A. Vehicle-to-Vehicle(V2V) Localization Techniques

The V2V localization technique is based upon the estimation of location considering sensor information from neighbouring vehicles. This method forms a vehicular ad hoc network (VANET) of vehicles where each vehicle know the location and movement of neighbouring vehicles. These cooperative method of localization is less costly than the existing costly LiDAR measurement based systems. The communication follows an extended version of the IEEE 802.11 called the IEEE 802.11p. This protocol follows periodical message passing of vehicle information of location, speed etc and event-driven messages of events of accident or breaking. There are different service messages used to communicate the vehicle to the infrastructure [14]. The self localization estimate of a vehicle is improved by multi-lateration using multiple GPS information from the neighbouring vehicles [15]. Rohani et al. [16] showed that the localization error can be improved from 6.75m to 3.30m using multi-lateration of GPS information of neighbouring vehicles. Fujii et al. [15] improved localization accuracy using the multi-lateration of the millimetre wave Radar sensor data. The accuracy of the distance estimation between the vehicle depends upon the number of the vehicle with V2V communication systems. Though all vehicle embedded with V2V technology only 50% of the vehicle can recognise nearby vehicles. Hence the number of vehicle and penetration rate of connected vehicle are nonlinear related to localization accuracy. Mattern et al. [17] testedV2V localization and showed on-board sensor produce good accuracy. Hence it can be concluded that the accuracy of localization of V2V cooperative localization system depends upon vehicle connected in the area and the number of the shared position. Ordonez et al. [18] changed the multi-lateration based system and added stationary vehicles to further improve accuracy of localization since stationary vehicle are more accurate in location estimation. Golestan et al. [19] improved the localization accuracy of V2V systems taking multiple GPS position and estimated the vehicles location from other vehicle using ToA and AoA estimation. The author achieved mean squared error of between 0.52m-1.65m. Another method of V2V localization using the weighted average of location of neighbouring vehicles proposed by Altoaimy et al. [20]. The author also consider signal-to-noise ratio and showed the localization error of 85cm for 20 vehicle and 25cm for 200 vehicles. Above mentioned research work relies on GPS so the accuracy can suffer in urban environments. Hence to maintain accuracy there is a need of development of fault tolerant localization system for the autonomous vehicle. Integrating GPS location with on-board sensor information is a solution for V2V localization [21]. Ibanez et al. [13] showed the limitation of IEEE 802.11p protocol simulating a 25% packet loss by a wall of the tree and concluded that to work a robust localization system for congested network alternative should be developed. Since current technology for localization are not enough for autonomous vehicular network, integrating on-board sensors may improve accuracy.

B. Vehicle-to-Infrastructure(V2I) Localization Techniques

The V2I systems comprises road side unit (RSU) at the fixed position, broadcasts information like location, traffic flow, weather condition. The vehicles communicate to the RSU for estimation of their location. The V2I system is more accurate, reliable and risk free than the V2V based localization system. However the V2I based localization system is costly for deployment due to the high number of RSU initial deployment is necessary to function this system. The performance of V2I system depends upon antenna height, tilt, packet length etc. [22]. Different localization estimation method has been proposed in literature. A low power, low cost, high bandwidth based impulse radio based UWB system is proposed by Hassan et al. [23] for V2I based vehicle localization. The author claims the system for perfect localization by placing RSU in 20m interval. AoA based localization technique is proposed by Fascista et al. [24] where the RSU broadcast beacons contains location information and angular information. The vehicles receive the beacon and estimate their location. Though this method shows superb localization accuracy but the error increase with the increase in the distance between RSU and vehicle. There is no need of high end on-board sensor requirement in the vehicle. Another ToA based localisation system based upon the two-way communication between RSU and vehicle is proposed by Khattab et al. [25] for V2I communication framework. The author simulated and achieved rms error up to 1.8m. Houdali et al. [26] presented V2I based localization system where they implemented the road white strips with passive transponder instead of RSU. These transponders are passive devices and only reflect the vehicle generated signal with location modification. The vehicle estimate their location up to 3cm accuracy as claimed by the authors. This method is cheap but the accuracy degrade as the transponder and vehicle distance increases. The fifth generation(5G) mobile network promise to give reliable, high throughput and low latency communication which may produce the better vehicle communication system [27] [28]. The cellular based localization method follows two approaches fingerprinting and triangulation. The triangulation uses signal path loss model for RSS and estimate the location. Though this method use low hardware, the accuracy is less [29]. In fingerprinting based localization approach the signal characteristic is used from diverse locations and accumulated in a database. When a new fingerprint collected from the unknown location, it is matched with the database to estimate the location [28]. Fingerprinting approaches are used in indoor scenarios with the accuracy up to 5m [30] and for outdoor the accuracy is up to 94m [31] [32]. Hybrid fingerprinting based upon GSM and GPS are proposed by Xue et al. [33].The author implemented first GPS based coarse localization followed by refining it with GSM information. However the major drawback of fingerprint based localization is costly implementation of periodic calibration of fingerprint database.

The combined approach of GPS,V2V and V2I with advanced sensor systems have also been reported in the literature [34] [35] [36]. Another approach of vehicular localization using visible light communication(VLC) have been reported in V2I [37] [38] and V2V [39] [40] [41] [42] frameworks. VLC based system uses light-emitting diode(LED) for transmission of data [43] [44] in vehicular network which is ranging up to 100m [45] in V2I and for V2V 50m [42]. VLC provide good accuracy in indoor scenario [46] but for outdoor the localization is less accurate due to interference and attenuation of the signal. Further researches in V2V scenario for vehicular localization is carried out for VLC scenario [42] [47].

C. Summary of Vehicular Localization System

Low latency is the major requirement for network traffic in both V2I and V2V systems. The network parameters like bandwidth and power should be optimised for scalable and reliable communication for IoV network. From the above mentioned reported researches it is found that cooperative localization perform well under good communication condition. In literature different results have been reported for different scenarios like urban and highway, etc. A generalised protocol is not available which is a limitation for vehicular networks. The privacy and security of the network is also challenging in these vehicular networks to avoid individual tracking of the vehicle. It can be summarised that the localization accuracy depends upon the sensor used and the level of penetration of the network from the existing localization techniques present in the literature. Line of sight, environmental impact and multipath effect are the major source of limitation of localization in IoV network.

III. System Model

Localization plays an important role in autonomous vehicular technology. The effective way for localization is through the cooperative network and this is achievable by the IoT enabled vehicular network called Internet of Vehicle. The network localization problem is explained in this section with measurement modules and performance bounds. This formulation is required for the analysis of localization algorithm.

A. Network Architecture

The network comprising reference nodes which know their location a priori denoted as A and the number of the unknown node N trying to estimate their position. For a node i its state can be represented as x_i and the position p_i. The state of the anchor node is denoted as a_i. The nodes are time synchronised embedded with one technology for range measurement and another for the communication technology. The network of nodes consists of the vertex set $\mathcal{V}$ and the links between nodes are represented as $\mathcal{E} \subseteq \mathcal{V}$. The bidirectional communication between node is represented as $(\mathcal{V}, \mathcal{E})$. The neighbour of a vehicular node i is represented by V_i and adjacent anchor node is represented by $\mathcal{A}_i$. Collection of adjacent vehicular nodes of the node i is represented as $\mathcal{N}_i$, where $V_i = \mathcal{A}_i \cup \mathcal{N}_i$

B. Measurement Model

The nodes of the network communicate with each other and find the location cooperatively. The measurement of the sensor nodes can be represented as follows:

$$\mathbf{y}_{ij} = \mathbf{f}\left(\mathbf{x}_i, \mathbf{x}_j, \mathbf{b}_{ij}\right) + \mathbf{n}_{ij} \tag{1}$$

Here $f(.)$ represents a function depends upon the state of both the nodes i and j and $\mathbf{b}_{ij}$ represents the nuisance parameter of appropriate dimension. The noise of the network is represented as $\mathbf{n}_{ij}$. The equation represents an abstract form of modeling where the parameter represent the form of available technology.

C. The CRLB and Fisher Information

The fundamental behaviour of the location estimators are analysed with the Cramer-Rao lower bound (CRLB). The CRLB is a derived quantity, and it is deducted from the Fisher Information Matrix (FIM). FIM measure the extent of average information an unknown parameter contain. For a parameter z, the FIM of z is represented by $J(z)$, a nonsingular matrix. It is represented as follows:

$$\mathbf{J}^{-1}(\mathbf{z}) \leq \mathbb{E}\left\{(\mathbf{z} - \hat{\mathbf{z}})(\mathbf{z} - \hat{\mathbf{z}})^{\mathrm{T}}\right\} \tag{2}$$

Where $\hat{z}$ is the estimator calculated considering all noise parameter's expectation values. The location estimator algorithm can be optimised and designed at both network and link level with the help of CRLB but it is inefficient for low signal to noise ratio(SNR). The nuisance parameters are unknown parameters which are not related to location of the nodes.

Between two nodes the clock bias an equivalent FIM is implemented called Equivalent Fisher Information Matrix

(EFIM) for the parameter $\mathbf{z} = \left[\mathbf{x}^{\mathrm{T}}, \mathbf{b}^{\mathrm{T}}\right]^{\mathrm{T}}$, Here x is connected to localization. Then EFIM is:

$$\mathbf{J}(\mathbf{z}) = \begin{bmatrix} \mathbf{J}(\mathbf{x}) & \mathbf{J}_{\mathbf{xb}} \\ \mathbf{J}_{\mathbf{xb}}^{\mathbf{T}} & \mathbf{J}(\mathbf{b}) \end{bmatrix} \tag{3}$$

Where $\mathrm{J}(\mathbf{x})$ represents information matrix x , $\mathrm{J}(\mathrm{b})$ represents FIM of the unknown parameter b , and J_{xb} represents the coupling of information. The EFIM of x , represented as $\mathbf{J}^{\mathrm{E}}(\mathbf{x})$, contains a matrix of all the parameters to calculate the CRLB of$x$. The position error bound (PEB) for the k th vehicle node can be calculated:

$$\mathrm{PEB}\left(\mathbf{x}_k\right) \triangleq \sqrt{\mathrm{tr}\left\{\left[(\mathrm{J}(\mathbf{z}))^{-1}\right]_{2\times 2,k}\right\}} = \sqrt{\mathrm{tr}\left\{\left(\mathrm{J}^{\mathrm{E}}\left(\mathbf{x_k}\right)\right)^{-1}\right\}} \tag{4}$$

The collaborative localization is effective or beneficial in a scenario is analysed by the CRLB. The collaboration of the network reduces the CRLB of the current network under different scenarios. Adding collaborative nodes in the network can lower the CRLB and hence improve the location estimator.

IV. Localization Method

The architecture of localization system for autonomous driving application is shown in Figure 1. The figure shows modules for map builder which comprises sub-module of lane detector and dead reckoning with the help of different sensors. The output of which is passed to a localizer which function as map matching from a map database. The output from the localizer is the control signal connected to different vehicle subsystem to control it.

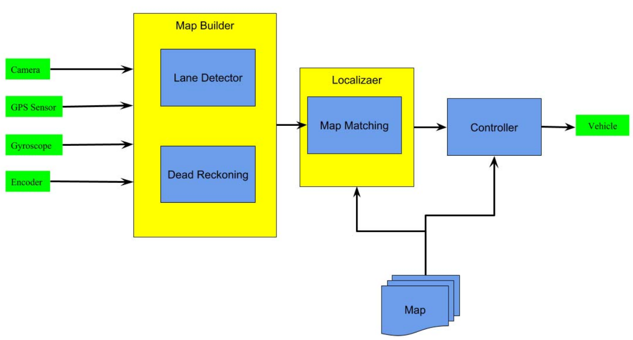

Fig. 1. Architecture for localization in autonomous vehicle

The map builder module receives sensor data and fuse the data to construct a map depending the operation module. The lane detector is a computer vision based algorithm which detects the lane marks in the vehicular network by inverse perspective transformation method. The dead reckoning module takes gyroscope and encoder data and helps in building a 2D map and path of the vehicle with heading angle. The location is estimated by the localizer module which utilise a map matching and filtering method using map database. Initially, the location of the vehicle is assumed as GPS location which is further refined by the map information from map builder module by filtering and matching algorithm. The algorithm matches the similar characteristics in the map to find its position. Matching process is erroneous hence additional filtering is added in this method. The controller module

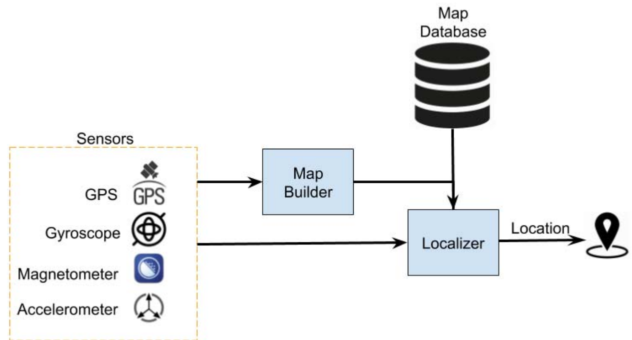

Fig. 2. Sensor data fusion algorithm for localization

uses information of localizer module and road geometry to control the movement of the vehicle. The control signals are sent to the servo motor for moving the steering wheel and other mechanical parts to maintain desired angle. The relative position and target information is used for maintaining vehicle stability and movement. The map database is a stored map file generated by map builder module while the vehicle is working in mapping mode. In mapping mode the vehicle is driven by a human driver to build the map and the map stored in the database. While operating the vehicle in autonomous mode the map file is loaded in memory to function the system.

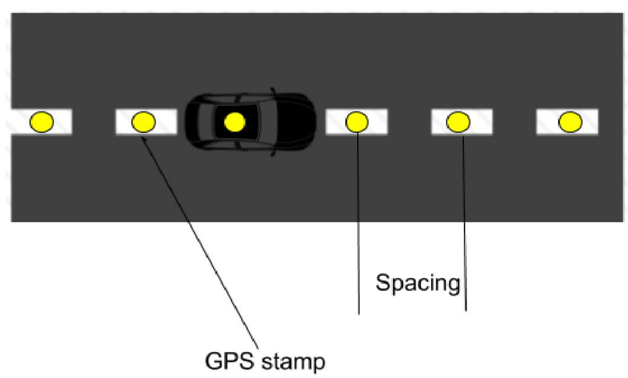

Fig. 3. Lane marking for map generation and positioning

The data fusion strategy to find the location of the vehicle is presented in Figure 2. The information from the four sensors of the vehicle is fused with prior lane structure and road geometry to maximise the accuracy of localization. The fusion is operated in cascaded scheme: first, the sensor data is used to build a lane structure called lane marking registry. Second, the data from lane marking registry, GPS location, gyroscope and encoder data is fused to estimate the position of the vehicle in reference of the map. The map is build before autonomous driving by a manual driving and a prototype of the vehicle movement is created and stored in map. This stored file is used later for localization in autonomous driving. The fusion method is comprising two steps

A. First step Fusion

The map builder module combine information collected from GPS sensor, odometer, gyroscope and encoder. The combined sensor data is used to build a 2D map of landmark. This map is stored in the form of a lane marking registry with a frame of reference. The difference between lane marking registry and map is stored in a database file called the map. This first step of data fusion of sensor data is done in two phases. The odometer and gyroscope data is fused for dead reckoning to form 2D path of the vehicle trajectory also called reference path. This reference path of the map is used to guide for the path for autonomous driving in the real-time scenario. In this reference path GPS information and lane marking are inserted when available. Inside the vehicle this information is transformed to vehicular reference frame by an inverse perspective transformation. This information is processed in the vehicle frame of reference.

B. Second step Fusion

The second step is the localizer module. This step uses filtering of information from the GPS and lane marking registry to update and refine the vehicles position. During the update the filter considers the uncertainty in the sensor and predict trajectory of the vehicle for next location. When the lane marking registry store enough information of lane the vehicle stop using GPS and localize only using map data.

V. Analysis and Result

The localization system showed in this paper is targeted to the autonomous vehicle application. This application requires high localization accuracy. So the radius necessary to maintain the vehicle in reference trajectory can be calculated by the following equation and is explained in the Figure 4.

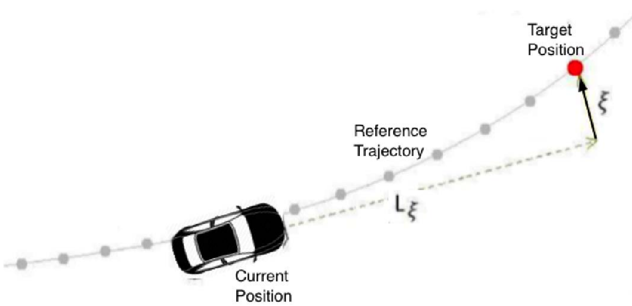

Fig. 4. Autonomous vehicle movement application of from localization information

$$R = \frac{\tilde{\zeta}^2 + L_\xi^2}{2\zeta} \quad (5)$$

Where ζ is vehicle longitudinal axis. The deviation can be calculated from the current state of the vehicle in reference path from the trajectory of the map. The analysis of localization accuracy is from the lateral error of the target point and the ground truth reference path. The lateral error of the MATLAB simulated version of this method is given in the Figure 5. The lateral error of the proposed method is superior than the GPS only method of localization in all time of reference.

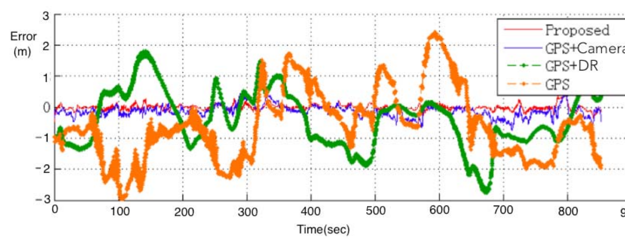

Fig. 5. Lateral localization error: A comparative plot with GPS, Dead Reckoning, Camera and Proposed method

VI. Conclusion

In this paper a cost effective cooperative sensor approach for vehicle localization is presented. This approach of localization is applicable for autonomous vehicle applications. The method is based upon two step data fusion model from vehicular sensors like the gyroscope, encoder, GPS sensor, camera etc. and a map which is build in manual driven trip. Though the system giving the satisfactory result but for autonomous vehicle scenario, the demand of accurate localization gives future direction of implementation of the system in low-cost hardware, dynamic utilisation of sensor data, improved filtering technique. The controlling module can be further improved in this system to control acceleration and breaking and obstacle detection for making the system completely autonomous.

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