A compact study on methodological insights on navigational systems in vehicular traffic system

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Article Info

Article history:

Received Jan 27, 2025
Revised Mar 18, 2025
Accepted Mar 26, 2025

Keywords:

Artificial intelligence
Methodologies
Navigation
Traffic
Vehicular

ABSTRACT

Navigation system has witnessed a significant inclusion of potential technological advancement in the area of vehicular traffic system. Since the last decade, there are various evolution of innovative techniques that has identified and addressed some serious problem towards vehicular navigation system. With a progress of time, artificial intelligence (AI) has evolved as contributory role model towards optimizing the performance of navigation system. However, still it is quite challenging to acquire a quick snapshot of overall stand of all such methodologies and its effectiveness. Hence, this paper presents a precise, compact, and highly crisp discussion of core taxonomies of methods towards improving navigation system. The paper also contributes towards highlighting their strength and weakness followed by updated research trend to understand the true picture. Finally, the paper contributes to highlight the critical trade-off and gaps.

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1. INTRODUCTION

Navigation system is specifically discussed with respect to vehicular traffic and is known to offer a system for assisting the user/vehicle for taking up safer routes, congestion-free travel path, and fuel-efficient journey [1]. Different types of technologies e.g., real-time data analytics, sensors, mapping software, and satellite assisted routing is used at present in navigation system design. The prime application of navigation system in vehicular traffic are route planning, management of traffic flow, management of autonomous vehicles, and fleet management. The significance of navigation system in vehicular traffic are manifold. An efficient navigation system offers autonomous alert system towards potential hazard e.g., adverse weather condition, traffic jam, and accidents. It also offers time efficiency and enhanced user experience with up-to-date maps and friendly user-interfaces. By significantly controlling and minimizing traffic congestion, potential carbon footprints towards transportation is reduced by efficient navigation system. However, there are various challenges encountered by navigation system viz. accuracy of real-time data, limitation of infrastructure, system integration, risk of cyberthreats, and over-reliance of a user. Such challenges have been identified by advanced research community where artificial intelligence (AI) is looked upon as a better path of solution towards improving vehicular communication system [2]. AI with its different variant of machine and deep learning algorithms has been contributing towards various complex world problems. Such algorithms are either used as standalone way, or in ensembled way, or in hybrid way and they have better capability towards addressing various ongoing research issues relating to navigational system.

Various related work has been reviewed in this process to understand the existing trends of methods. The work presented by Stateczny *et al.* [3] have discussed about different types of underlying approach of vehicle navigation system. Li *et al.* [4] have presented vivid discussion on technologies related to autonomous navigation system with a special focus on unmanned vehicles. Elaboration towards data transmission methods in network traffic and its possible impact on navigation system is studied by Festa *et al.* [5]. Jeong *et al.* [6] discussed various existing communication methods as well as networking techniques towards vehicular communication that is necessary backbone of any navigation system. Kamath *et al.* [7] have used deep learning-based methods towards improving the knowledge sharing process in navigation system.

The research problem that have been noted are as follows: i) existing review papers are quite broader and doesn't narrow down to understand shortcomings of existing techniques on actually demanded navigation system, ii) majority of current papers using AI reports of final conclusive accuracy outcomes without discussing the method adopted to overcome the internal limitation/constraints factors itself towards dynamic traffic, iii) irrespective of availability of various study approach, still the trade-off factors and potential gap relating to implication of machine learning on navigation system is not studied well enough.

The prime aim of the study is to present an insight towards existing form of research methods targeting to improve the navigation system used in vehicular networks. The value-added contribution of study are as follows: i) the study presents a clear-cut briefing of existing approaches towards improving navigation system, ii) different taxonomies towards currently techniques have been presented with respect to strength and weakness, iii) exploratory study towards updated research trends has been carried out to discuss the degree of emergence of methods, and iv) exclusive highlights of identified research gap and trade-off have been discussed.

2. METHOD

The proposed review work has been carried out considering a research methodology shown in Figure 1. According to this methodology, the initial step is towards acquiring primary data from various online technical archives using keywords. The common keyword is "navigation" which is searched in combination with various other keywords viz. "vehicular system", "direction", "route planning", and "traffic management". The primary data are preliminary scanned for their title, abstract, and contribution mentioned in last part of introduction section. All the redundant articles are eliminated followed by secondary screening where the shortlisted papers are reviewed with special focus on its algorithmic steps, implementation strategies, accomplished outcomes. The core idea is towards understanding the impact of adopted methodologies towards the claimed study outcomes. In this process, the study is carried out considering inclusion and exclusion criteria which defines the ruleset for involvement and shortlisting of papers. The inclusion criteria for this study are all research journals with discrete results with comparison, definitive highlights of simulation results, and clear definition of algorithmic steps. The exclusion criteria for this study are papers published before 2019, any conference papers, and theoretical papers or papers without discrete outcomes or justifications. All the final outcomes are finally reviewed in order to arrive at conclusion information about trade-off and research gap.

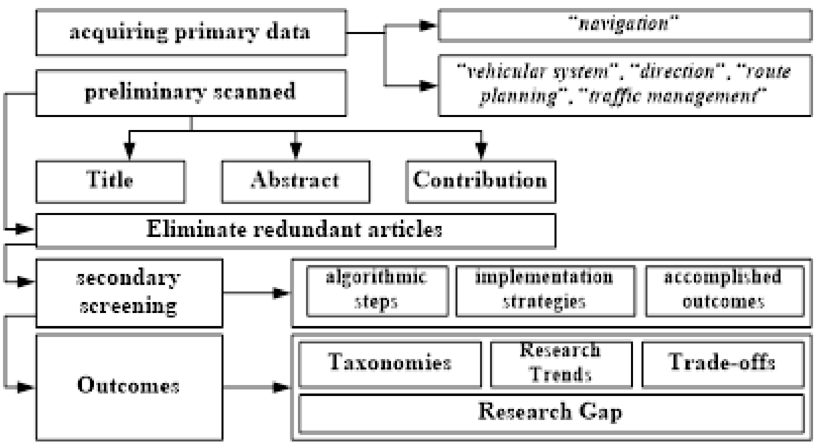

Figure 1. Research method for study

3. RESULTS

This section presents discussion of the outcomes accomplished from the current review work to understand its strength and weakness associated with its implementation logic. Further, discussion of research trends has been carried out that offers more clear stance of existing methodological category as well as reachabilty of solution towards current addressed problems. Finally, this section discusses about the identified trade-off and gaps for more clear visualation of the review findings.

3.1. Studies towards navigational system

Adoption of global positioning system (GPS) is witnessed in work of Aslinezhad *et al.* [8] who have used neural-network based error compensation scheme. The study uses Kalman filter (KF) towards localization using inertial and GPS-based navigation system. The second methodoogy potentially witnessed in current time is related to usage of vision-based methods in navigation as noted in work of Yue *et al.* [9] and Baldoni *et al.* [10] towards autonomous vehicle in navigation. The study has assessed the vehicular direction along with lateral offset obtained from global navigational satellite system (GNSS) images. The work of Latif *et al.* [11] have used standard geometric-based tracking algorthm to evaluate the necessary steering angle towards specific path in navigation.

The third form of methodology is related to route planning. By creating a navigational methodology based on the assessment of received signal strength (RSS), Ahmad *et al.* [12] have tackled the localization problem. Cramer rao lower bound (CRLB) is used to obtain a closed-formed solution. Ballardini *et al.* [13] used the hidden Markov model (HMM) to frame the foundation of a driving assistance system, demonstrating the impact of vehicle localization on navigation systems. The goal of the work is to locate consistent lane estimates in situations where the quality of the data is not optimal. In a contributing work, Cai *et al.* [14] introduced a unique route planning system that uses the A* algorithm to find insight into the traffic condition at coordinates. A path planning scheme has been presented in the study, where the location problem is resolved using the Monte Carlo method and the navigational mapping performance is optimized using extended Kalman filter (EKF). An autonomous navigation system designed to become independent of map apriori information while navigating in intersection areas was presented by Ort *et al.* [15]. The model can effectively plan its trajectories without the use of an external localization system.

The fourth frequently witnessed methodology is related to experimental modelling. A simplified navigation system has been framed by Lopez *et al.* [16] in order to address the velocity correlation with the road's curvature. By acquiring a reference curvature system and avoiding collisions of any kind, the paper has made a contribution to a reactive control mechanism. A novel navigation system design has been proposed by Otaki *et al.* [17] with the goal of encouraging users to move by foot. The non-shortest route-based method and other multi-day navigation methods have been examined in this paper. The distribution of speed probability for route planning with dynamic attributes has been examined by Vitali *et al.* [18]. In addition to adopting an autotuning library with flexible dynamicity, the author has created a probabilistic model to solve the dynamic routing problem. A navigation system designed specifically for blind individuals was presented by Wang *et al.* [19], taking into account the importance of touch-sensitive spatial landmarks. The study model produces a map matching and path planning method tailored for blind users that takes geometric constraints into account. Digital twins have been used by Wang *et al.* [20] to create a smart mobility-based environment that will make navigation easier. The model's effective navigation system is evaluated through simulation research and field testing. A multi-agent system for a cost-effective collision-free path formulation has been proposed by Yao *et al.* [21]. The approach, which is based on a navigational mechanism based on social awareness, is presented as a path optimizer.

Finally, machine learning methods are another prominent methods used towards improving navigation system. By combining the A* search algorithm with a machine learning algorithm, Li *et al.* [22] have solved the navigational issues related to cars that use electric charging. Cooperative localization with EKF has been used by Oliveros and Ashrafiuon [23] to address multi-vehicle navigation systems and their autonomous challenges. Sun *et al.* [24] adoption of machine learning for inertial system-based navigation involves using EKF for error correction after machine learning is used to capture three-dimensional landmark information. Chen *et al.* [25], which focuses on mapping potholes, highlights that obstacle detection is another crucial component of the vehicle navigation system. The model employs vibration analysis and machine learning to analyze a laser-scanned image of a road. A deep learning-based method for creating a navigational controller system tailored to autonomous unmanned vehicles has been presented by Chen *et al.* [26]. By combining data from GNSS, odometer, and inertial sensor, Du *et al.* [27] have developed a novel navigational scheme. In comparison to the majority of schemes that use EKF, the scheme's results are superior because it makes use of long short-term memory (LSTM) to optimize navigation performance. Manikandan *et al.* [28] conduct additional research on obstacle avoidance systems, using deep learning algorithms to make decisions about steering control for self-driving nodes. Papagiannis *et al.* [29] have presented a novel navigational model that incorporates a number of critical multi-attributes for resourceefficient vehicle navigation. Bank angle, road inclination, and vehicle velocities with lateral-longitudinal perspective are the characteristics that are used. Neural networks are also used in the model to optimize this estimation technique. Table 1 summarizes the existing studies towards navigation system.

Table 1. Summary of methodologies of navigation system

Authors	Method	Advantages	Limitations
[8]	GPS-based navigation	- Maximized accuracy especially in outdoor.	- Performs poorly in terrain with poor satellite visibility
		- Up-to-date routing due to real-time data	- Prone to interference due to taller structures.
[9]-[11]	Vision-based navigation	- Simpler interpretation of real traffic conditions.	- Computationally expensive, demand expensive sensors.
		- Easily detect any obstacles	- Influenced by extreme conditions of weather
[12]-[15]	Route planning	- Offers high-resolution and accurate mapping	- Increased cost and complexity
		- Effective detection of traffic events in real-time.	- Higher dependencies on infrastructure and other vehicle
[16]-[21]	Experimental modelling	- Effectively detect events	- Detection range fluctuates
		- Can detect traffic differences.	- Lower quality of traffic data
		- Works well in all traffic condition	- Demands extensive infrastructure support
		- Simplified detection and tracking performance	- Can only detect in short ranges
		- Aggregate real-time traffic data from all connected vehicles.	- Inconsistent data quality.
		- Useful towards adverse traffic events	-Extensive privacy concerns
		- Facilitates data exchange in real-time	-Highly dependent on infrastructure
		- Enhanced traffic flow and supports collaborative decision-making.	- Have privacy concerns
[22]-[29]	Machine learning methods	- Significanty optimize routing, enhances navigation using traffic patterns of real-time	-Demands intensive computational resources, higher dependency on voluminous training data
		- Highly adaptive systems	- Biased training data.

3.2. Trend analysis

A trend towards publications of the research work is carried out to understand various types of navigational system being surfaced. In this perspective there are two schemes being noted where the first schemes relates to AI based approaches while second scheme relates to non-AI based approaches are shown in Figure 2. Figure 2(a) and Figure 2(b) showcases existing publications on AI and non-AI based approaches undertaken towards navigational system respectively. From Figure 2(a), it is noted that there are only 673 relevant publications in presence of 8288 research papers using AI schemes. According to Figure 2(b), there are 2060 relevant research papers in presence of 6,769 total research papers relating to non-AI based approaches towards navigational study. Further, Figure 2(c) shows that out of 12,155 papers, there are distinct 4,904 research papers who has addressed to some of the common problems relating to traffic-prone issues in navigational system.

3.3. Trade-off and gap identification

After reviewing the current approaches towards existing studied various strength as well as loopholes has been witnessed which is mainly with respect to trade-off factors. With an increasing demands of autonomous applications in vehicular system, it is necessary to identify such trade-off for better exloration towards future research work. Hence, this section highlights all the significant trade-off as well as the potential gap identified from current study:

a) Aggregation of real-time data and complexity
- Trade-off: accurate decision-making requires real-time data collection from cameras, GPS, traffic sensors, and other sources. However, it is computationally costly to process and analyze this data in real-time.
- Research gap: finding a balance between computational efficiency and real-time responsiveness is still difficult, particularly as the amount of data grows due to the use of internet of things (IoT) and connected car technologies.

b) Controlling via centralized and decentralized way
- Trade-off: coordinating and controlling traffic management decisions is made simpler with centralized systems. In a crisis, they might become overburdened and experience single points of failure.

- Research gap: although decentralized systems (such as vehicle-to-vehicle or vehicle-to-infrastructure communication) may be more resilient and scalable, they also need intricate coordination mechanisms and might not be as good at managing unforeseen incidents or traffic disruptions.

c) Vehicular autonomy and infrastructure
- Trade-off: the implementation of smart infrastructure (such as traffic lights, cameras, and sensors) may have an impact on how well vehicle traffic management systems work. But putting such infrastructure in place on a large scale can be costly and challenging.
- Research gap: the development of autonomous vehicles raises the issue of how infrastructure ought to change. Should the emphasis be on enabling vehicle autonomy with little dependence on external infrastructure, or should it be designed to function with both human-driven and autonomous vehicles? The solution is still unknown, and moving toward a completely autonomous system has its own set of difficulties.

d) Traffic management via dynamic and static infrastructure
- Trade-off: a lot of current systems are dependent on fixed infrastructure, like traffic lights and sensors, which are difficult to modify in response to abrupt shifts in traffic patterns. However, dynamic, flexible systems (such as real-time traffic rerouting or adaptive traffic signals) need sophisticated algorithms and can be more costly and complicated to implement.
- Research gap: one unresolved challenge is creating systems that can swiftly and efficiently adjust to traffic conditions in real time across expansive urban environments without necessitating continual human intervention or causing network instability.

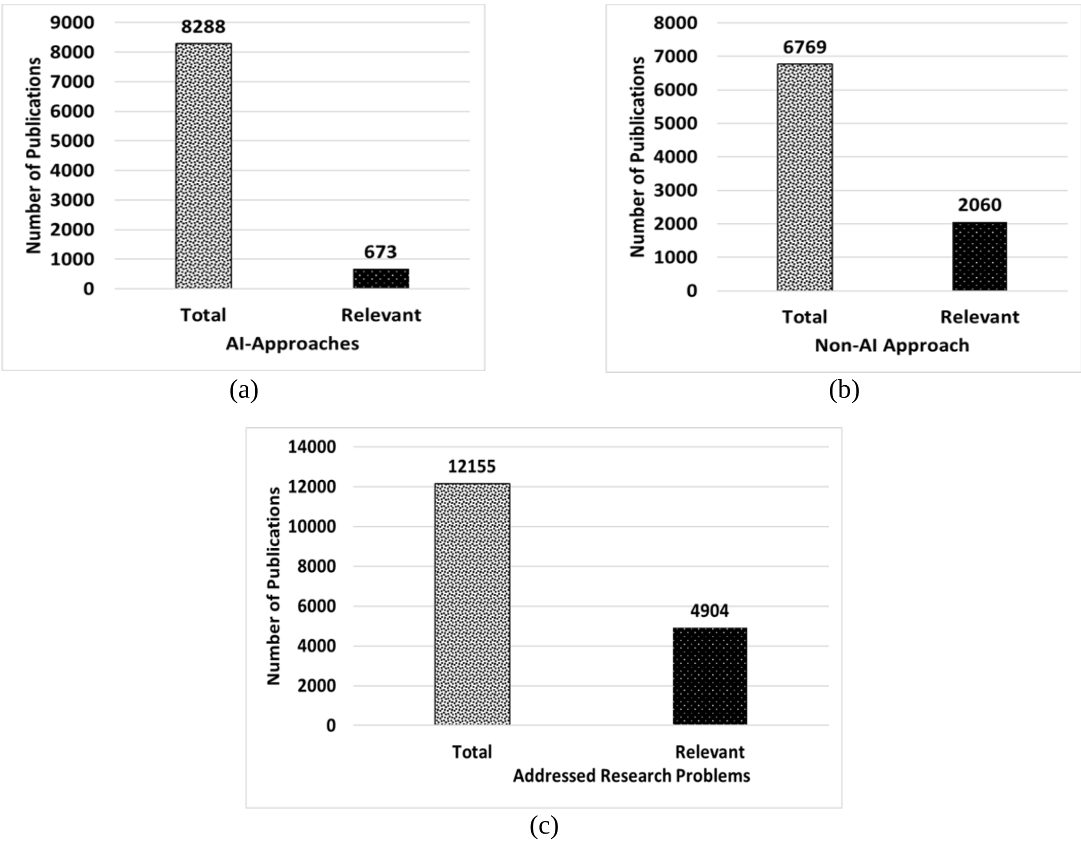

Figure 2. Analysis of research trend; (a) AI-based approaches, (b) non-AI based approaches, and (c) addressed research problems

4. CONCLUSION

This current paper has presented a crisp discussion related to the current form of methodologies adopted in existing system towards navigational system. The contribution of this paper is as follows: i) the study presents a crisp insights on navigational system methods on various techniques with respect to their strength and weakness, ii) the discussion of the adopted methodologies are carried out with respect to various categories viz. GPS-based navigation, vision-based navigation, route planning, experimental modelling, and machine learning methods, iii) the review study has also exhibited the prominent findings of research trends to showcases degrees of adoption of AI and non-AI techniques as well as different number of problems being addressed, iv) the paper has also identified the significant issues in form of research trade-off and finally evolved into converged highlights of research gap. The future work will be carried out in the direction of addressing the above-mentioned research trade-off and meet the research gap. For this purpose, a novel machine learning approach will be developed that can offer optimized analysis on traffic data which can further facilitate autonomous navigation system considering extensive geographical location without much dependencies on infrastructure.

ACKNOWLEDGEMENT

We wish to confirm that no known conflicts of interest are associated with this publication and all the authors have contributed equally.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Mayuri Kundu		✓		✓		✓		✓	✓	✓	✓	✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author.

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