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Overview

Smarter and more connected: Future intelligent transportation system

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ABSTRACT

Emerging technologies toward a connected vehicle-infrastructure-pedestrian environment and big data have made it easier and cheaper to collect, store, analyze, use, and disseminate multi-source data. The connected environment also introduces new approaches to flexible control and management of transportation systems in real time to improve overall system performance. Given the benefits of a connected environment, it is crucial that we understand how the current intelligent transportation system could be adapted to the connected environment.

1. Introduction

Analysis and understanding of transportation issues are often constrained by domain-dependent data sources. Recent emerging technologies toward a connected vehicle-infrastructure-pedestrian (VIP) environment and big data have made it easier and cheaper to collect, store, analyze, use, and disseminate multi-source data. A connected VIP environment also makes the system more flexible so that real-time management and control measures can be implemented to improve system performance. With a connected environment, vehicles, infrastructure, and pedestrians can exchange information, either through a peer-to-peer connectivity protocol or a centralized system via a 4G or more advanced telecommunication network (VIP environment). Such technology is regarded as one of the most potentially disruptive technologies for the urban eco-system. The interaction and exchange of information can occur vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), pedestrian-to-infrastructure (P2I), or vehicle-to-pedestrian (V2P). Given the benefits of a connected environment, and considering its unique characteristics, it is crucial to understand how current intelligent transportation systems could be adapted to work with the connected environment. This paper aims to: (1) review current trends in intelligent transportation systems (ITSs) and smart cities; and (2) offer insights on the introduction of connected VIP environment into these systems.

The paper is organized as follows. The next section is a review of the current trends in intelligent transportation systems. In Section 3, we discuss smart cities and related artificial intelligence (AI) techniques. The concept of a connected environment is described in Section 4. Finally, Section 5 offers insights into future ITSs and smart cities.

2. Current trends in intelligent transportation systems (ITSs)

Congestion, accidents, and pollution issues due to transportation are becoming more severe as a result of the tremendous increase in various travel demands, including vehicular traffic, public transportation, freight, and even pedestrian traffic. To resolve such issues, ITSs have been developed that are able to integrate a broad range of systems, including sensing, communication, information dissemination, and traffic control. Three essential components are necessary for any ITS to perform its function(s): data collection, data analysis, and data/information transmission.

Data-collection components gather all observable information from the transportation system (e.g., traffic flow at a particular point of the road network, average travel time for a particular road section, number of passengers boarding a transit line, etc.) for further analysis of the current traffic conditions. Traditionally, inductive loop detectors [1,2], which detect the presence of vehicles based on the induced current in the loop with passing vehicles, and pneumatic tubes [3], which detect the presence of vehicles based on pressure changes in the tube, have been used to collect basic traffic information such as traffic volume and spot speed. However, because of their high implementation cost and impact on traffic during implementation, these methods are becoming less popular, especially in congested areas.

Due to advances in sensing and imaging technology, video cameras and radio-frequency identification (RFID) scanners are increasingly being considered for use in traffic data collection. Cameras can be installed at different locations in the network to collect traffic videos. The videos are then analyzed using specifically designed image

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processing software (e.g., Autoscope) to determine information such as traffic flow, speed, vehicle types, etc. [4,5]. In this context, automatic license plate recognition [6,7] is one crucial area of research, as through the recognition and matching of license plates, it can provide additional information such as selected paths and travel times. On the other hand, radio-frequency identification data (RFID) can commonly be obtained at locations that accept contactless payment (e.g., Autotoll and Octopus systems in Hong Kong), or for freight transport. Through the matching of unique RFID, different traffic-related information, such as path choice and travel time, can be extracted [8,9].

Recently, due to increasing penetration of smartphones and advanced communication technologies, Global Positioning System (GPS) data [10,11], media access control (MAC) addresses from Bluetooth and WiFi components [12,13], and mobile phone data [14,15] are becoming available for the analysis of traffic conditions or even travel behavior. Compared to the data sources listed above, these new types of data are more at the level of the individual, as such devices are usually personalized, and capable of continuous tracking (e.g., GPS and mobile phone data). With such characteristics, more detailed and/or behavioral-related analysis could be conducted.

Data analysis components of ITSs aim to provide various information and management/control measures, using the traffic data collected from the various sources discussed (e.g., inductive loop detectors, GPS, etc.). Traditionally, predefined and pre-calibrated models, such as traffic equilibrium models [16,17], flow models [18,19], and various models for signalized intersection [20,21], have been adopted to evaluate traffic conditions and provide the necessary response. Recent improvements in computation power and the need for more detailed evaluation have led to the development of micro-simulation and agent-based models in data analysis components [22,23]. Due to the introduction of new sources of data, these models have been extended to effectively use the new data to improve the accuracy and detail of evaluations [8,13,14,24].

The data/information transmission components of ITSs help communicate the collected data to operation centers for evaluation and disseminate information, and/or management/control measures, to travelers and infrastructures. Methods for transmitting collected data have evolved from wires to optical fibers to wireless networks (e.g., 3G/4G, WiFi, etc.) with cloud platforms. For the dissemination of information and control/management strategies, methods have evolved from traditional traffic signs and radio broadcasting to variable message signs [25], mobile applications [26], and in-vehicle information [27] by taking advantage of improved communication technologies.

With these basic components, ITSs can be categorized into one of two categories based on their functionalities. These are Advanced Traveler Information Systems (ATIS) and Advanced Management Systems (AMS). The details of each are presented below.

Advanced Traveler Information Systems – ATISs aim to help travelers make travel decisions (e.g., mode choice, route choice, departure time choice, etc.) by providing various types of information (e.g., travel time, wait time, available parking). Of the various implementations, travel time estimation/prediction [8,10,28], and route guidance systems [29,30] are the most commonly studied areas as they can affect travelers' choices directly, especially route choice. With the advancement of the data-collection methods and communication technologies described above, travel time and route guidance information provided can be in a more accurate and real-time manner. With the additional sources of data (e.g., GPS data, mobile phone data, etc.), other real-time information is also available to travelers. For example, analysis of road-condition images from drivers taken automatically from smartphone applications can be used to determine available roadside parking in real time [31]. Another example is the prediction of bus arrival time from information transmitted by bus passengers through mobile phone signals across different cell towers [32].

Advanced Management Systems – AMSs aim to control or manage different infrastructures and operators within the transportation system under different situations to ensure the efficiency and safety of the transportation system. In the literature, such control/management methods are applied to arterials [33], freeways [34], freight transport [35], transit services [36], and incident/emergency situations [37]. With enriched data sources, improved data resolution, and enhanced information dissemination methods, more real-time and detailed management is possible. For example, Fu and Yang [36] proposed bus-holding control strategies based on real-time bus location information to regulate bus headway at specific stops. Although these researchers have only validated their models in simulation experiments, they provide good insight into how new sources of information could be used in transit management. Kurkcu et al. [37] provide another example by using open data sources and social media data for incident detection, which is the crucial first step of incident-management procedures.

3. Reviews of smart cities and related artificial intelligence techniques

The ITSs introduced in the previous section aim to solve transportation-related issues and improve the overall efficiency of transportation systems. These ITSs fall under the category of smart mobility within the framework of smart cities, which is gaining its concerns in the recent decades. In the literature, there is not yet consensus as to what constitutes a smart city, and there are diverse definitions [38,39]. For example, Hall [40] suggested that a smart city would monitor its components (e.g., roads, buildings, etc.) to better optimize its resources, plan preventive maintenance activities, and monitor security, while maximizing services to its citizens. Lombardi et al. [41], on the other hand, proposed that smart cities are those that use information and communication technology (ICT) on human capital, social and relational capital, and environmental issues. The definitions also depend on the background of stakeholders and the focus of the government [42]. For instance, academia considers improving quality of life to be the major goal of a smart city, while stakeholders in a private company might opt for efficiency as the primary goal [42]. Despite this diversity of definitions, using advanced electronic/digital technology (e.g., ICT), embedding ICT or other electronic hardware into city infrastructure, and improving stakeholders' interests in different aspects of the system are the three common characteristics or dimensions of the smart city.

Concerning functionalities, smart cities can be divided into six different components [39,41,43,44]: smart governance, smart economy, smart human/social capital, smart environment, smart living, and smart mobility. *Smart Governance* aims to use ICTs to enhance the efficiency and transparency of public sector organizations in the management of public resources, and to encourage public participation in decision-making. The goal of a *Smart Economy* is to employ ICT and related technologies to improve productivity in the manufacturing chain and to enhance and fortify online transactions for the promotion of e-commerce. *Smart Human/Social Capital* aims to improve the education level and active public participation of citizens through the provision of enriched information generated from the other components of the smart city. The goal is also to collect individual views and attitudes, as these data are some of the best information any government can obtain. The objective of a *Smart Environment* is to reduce pollution and resolve other environmental issues with the ultimate goal of improving urban/city sustainability through the use of technology. *Smart Living* seeks to improve quality of life (e.g., security, housing quality, social cohesion, etc.) through the implementation of advanced technologies within cities and infrastructures. *Smart Mobility*, sometimes considered under the rubric of smart living due to the focus on the efficient transport of people, attempts to use advanced ICT to optimize logistics and transportation systems and provide efficient, safe, and environmentally friendly services for passengers and freight. Based on these components, various indicators (e.g., local accessibility, productivity, emissions, etc.) have

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