Applications of Ubiquitous Computing in the Transportation Domain

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***Abstract*— Ubiquitous computing is embedded in people's daily lives as people engage with computational devices and systems to perform tasks without being aware of the engagement with the computational infrastructures. Its core concept is to interconnect the physical and digital worlds seamlessly. By implementing ubiquitous computing in urban infrastructure, ubiquitous cities can be established. In ubiquitous cities, information technology is seamlessly embedded in municipal entities to provide services. As transportation is one of the cities' significant domains, ubiquitous transportation is an integral component of ubiquitous cities. Researchers have proposed systems and ideas regarding the application of ubiquitous computing in the transportation domain. There are already implementations and applications of ubiquitous computing in the transportation domain, such as the Global Positioning System (GPS) and connected vehicles using Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Everything (V2X) communication. In this research, the authors have critically reviewed the existing and proposed applications of ubiquitous computing in the transportation domain, focusing on the impact of these applications on people's daily life.**

Keywords*— *Ubiquitous Computing, Ubiquitous City, Ubiquitous Transportation, Global Positioning System (GPS), Connected Vehicles)

I. Introduction

The term "ubiquitous computing" was invented by Mark Weiser in 1988. (Ekman et al. (2016) (Yong et al. 2022) defined ubiquitous computing as "a sociocultural and technical thrust to integrate and embed computing pervasively, to have information processing thoroughly integrated with or embedded into everyday objects and activities, including those about human bodies and their bodily parts". In short, the main objective of ubiquitous computing is to implement computing technologies seamlessly into physical objects in the world, allowing users to interact with computing infrastructures in a more natural and non-intrusive method. Ubiquitous computing provides services to users without perceiving that they are interacting with those technologies (Yong et al. 2022).

Ubiquitous computing enables the intimate linking of the physical and digital worlds, leading to novel computing interactions. This linking leads to the automatic identification capability, which gives rise to the emergence and development of ubiquitous computing in terms of its elements and complexity (Konomi & Roussos, 2007).

The research paper is structured into seven sections. Section I is the introduction. Section II provides an overview of the ubiquitous city and ubiquitous transportation. Section III insights into Global Positioning System (GPS) and its related services. Section IV discusses universal passenger services in the public transportation environment. Section V covers autonomous vehicles and connected vehicles. In section VI, an illegal vehicle parking detection system is critically analysed. Finally, section VII concludes the research paper based on the reviewed studies.

II. Ubiquitous City and Ubiquitous Transportation

A. Ubiquitous City

A ubiquitous city is an advanced version of a smart city – a smart city has programmable devices and electronic services to replace conventional urban services. In contrast, a ubiquitous city has embedded sensors in everyday objects and interconnected smart devices that allow people to perform desired tasks anytime and anywhere (Ghaemi Rad et al., 2018). Ubiquitous cities are operationalised by ubiquitous computing, meaning that objects are embedded with nearly invisible computing technologies, if not true. The elements of a ubiquitous city are digital devices that allow continuous interactions by users at anytime and anywhere. Meanwhile, digital networks connect all entities and may also offer services. The main objective of ubiquitous cities is to enhance the quality of services. Ubiquitous cities may also improve the economy as information and communication technologies (ICT) are embedded in urban facilities and municipal infrastructure.

To develop ubiquitous cities, the elements of smart cities should be further improved. One of the significant elements is transportation. Ghaemi Rad et al. (2018) listed some criteria for achieving ubiquitous transportation, including the capability to provide essential transportation information, technical monitor the status and operating conditions of vehicles, predict traffic flow, provide early disaster warnings, and manage events smartly, as well as the existence of smart tolls, automatic parking systems, parking charge payment systems, and V2V and V2I networks. These ubiquitous infrastructures and systems can address issues like pollution and traffic congestion, enhancing city transportation. Furthermore, ubiquitous transit can also lead to a greener environment and improve the quality of life.

B. Ubiquitous Transportation

Authors (Lee et al. 2008) defined ubiquitous transportation as "the transparent service environment with the omnipresent and transcendent transportation intelligence in all transportation-related objects, which makes transportation safer and more efficient". In other words, ubiquitous transportation refers to the ubiquity of transcendent transportation intelligence by applying ubiquitous computing in the transportation environment. In short, ubiquitous transportation is achieved by implementing ubiquitous computing in the transportation domain.

Many implementations of ubiquitous computing in the transportation domain enhance people's lives. The following sections will discuss and analyse different ubiquitous computing applications in transportation.

III. Global Positioning System (GPS)

GPS is one of the most popular applications of ubiquitous computing in transportation. It possesses one of the main characteristics of ubiquitous computing, which is context awareness. GPS is a context-aware system focusing on location awareness that captures information using sensors and modules, such as GPS satellites, proximity sensors, cameras, and mobile phone towers. Proximity sensors allow GPS to determine a user's location and offer services according to the user is detected location (Meshram et al., 2016).

In short, GPS is for tracking locations. Nowadays, it is widely used in the transportation domain for tracking and monitoring vehicles. Various systems are created and developed to provide the services. GPS is integrated into different applications for specific uses, such as in-car navigation, fleet management services, marine navigation, and so on (Varshavsky & Patel, 2018). General Packet Radio Service (GPRS) is commonly used to retrieve data from GPS devices.

GPS-related services are usually provided through a website or software. For instance, navigation applications like Google Maps and Waze show a user's real-time location on a map. Additional functionalities and features are provided in these applications also. For example, these navigation applications allow users to search for locations, show different routes to a selected area, and provide directions for navigating to the desired location.

GPS is integrated into various applications to enhance user experiences too. For instance, food delivery platforms and applications allow users to check the real-time location of their assigned drivers who deliver their food. This acknowledges the users about the current location of their food and the estimated arrival time, which indirectly reduces the users' anxiety during the waiting period after placing their orders.

The wide usage of GPS and GPS-related services reveals that GPS benefits various areas. For example, in the transportation domain, GPS plays a vital role in providing location information and tracking and monitoring the location of a person, an item, or a vehicle. Moreover, it is ubiquitous because the data collected by GPS can be accessed anytime and anywhere.

IV. Ubiquitous Passenger Services

Public transportation is vital in more sustainable, greener, and livable cities. Public transportation systems can be improved by offering valuable passenger services. Furthermore, passenger services in the public transportation environment can be ubiquitous and interactive by implementing ubiquitous computing. This will increase the attractiveness of public transportation and enhance people's lives. This may also lead cities towards achieving the goal of being ubiquitous.

A. Ticketing

Tickets are the central element in the public transportation environment; thus, ticketing is one of the essential services. Mobile ticketing is a standard service that allows passengers to purchase and show tickets for public transport through a mobile device. In the public transportation environment, mobile applications offer users to buy public transport tickets represented by QR codes or barcodes that are scannable by specific validation applications (Baldauf & Tomitsch, 2020).

This significantly increases the efficiency of ticket purchasing as passengers do not need to purchase tickets at particular counters. In addition, digital ticketing also improves the operational efficiency of public transportation due to the reduction of required human resources, such as ticket inspectors and workers at counters.

Moreover, instead of offering ticketing services for specific public transportation, it is more reasonable to integrate all ticketing information and provide a comprehensive ticketing service for several, if not all, public transportation. This is because passengers might need to take different transportation modes to reach their destination and thus purchase multiple tickets. It will be easier for them to buy all tickets in a single mobile application. Therefore, mobile applications that integrate multiple ticket providers and offer access to all public transportation can support passengers with intermodal routing (Baldauf & Tomitsch, 2020). Compared to using and switching between different mobile applications, a mobile application offering services for all public transportation is more user-friendly and valuable. This will enhance passengers' experiences in using public transportation and indirectly increase the attractiveness of public transportation.

B. Travel Information

In the public transportation environment, real-time information, such as schedules and timetables, is vital to passengers. Hence, real-time information on public transportation should be easily accessible to passengers. The information can be provided through interactive public screens and mobile applications.

Public screens at stations or stops of public transportation can be utilised to provide passengers with helpful information. Interactive screens can offer features such as browsing schedules and timetables, navigating to the current station or stop, navigating for intermodal routing, showing a countdown timer for the next public transportation arrival, and so on. Compared to non-interactive display screens, interactive screens can offer passengers more features and information. Thus, passengers can browse desired information quickly. This will increase the satisfaction of passengers in obtaining information about public transportation.

Some interactive screens also offer features that support users with physical disabilities. For instance, the read-aloud functionality supports visually impaired users, and the capability to move contents on the screens towards the bottom of the screens through a click on a button supports users in wheelchairs (Baldauf & Tomitsch, 2020). These additional features make the service support a more comprehensive range of users. This will result in more sustainable public transportation systems.

Mobile applications providing public transportation information enable ubiquitous transportation as users can access the information at anytime and anywhere. In addition, extra features can be offered in mobile applications, such as push notifications regarding the selected public transportation route – countdown timer, expected delays, incidents, and others. This method provides users more mobility and flexibility to retrieve information than public screens.

Nevertheless, both methods allow user interactions with the system providing information. This offers interactive passenger services to obtain up-to-date information about public transportation.

C. *Intermodal Route Planning, Navigation, and Routing*

Intermodal route planning, navigation, and routing is also a prominent feature in mobile applications offering services for passengers with intermodal travelling.

The intermodal route planning feature enables users to plan for their routes with one or more transportation modes, including train, bus, car, bike and walking. In addition, some mobile applications also offer the functionality of filtering intermodal routes to the desired destination. This offers users multiple route options and allows them to select based on their requirements and preferences. With features providing services regarding intermodal routes, passengers can easily plan, navigate, and route their trips with intermodal routes.

However, the increasing manifold information and mode of transportation like sharing bikes due to the present "mobility as a service" trend might overwhelm users with much information. The solution to this challenge is to replace the current pre-trip planning with on-trip guiding, such that smart routing algorithms provide real-time information and options to users when they arrive at a particular destination (Baldauf & Tomitsch, 2020). This novel approach is significantly feasible in improving user experiences in public transportation as users will need to select an option at a time during the travelling period rather than making decisions for the entire trip before travelling. Moreover, this feature offers users more reliable routes as the information is always up-to-date. Integration of real-time and up-to-date information on various transportation modes and smart algorithms is needed to offer this feature.

V. Autonomous and Connected Vehicles

A. *Autonomous Vehicles*

Autonomous vehicles may be a key to ubiquitous transportation and ubiquitous cities. This leading innovation in the automotive and engineering fields is expected to enhance operational performance, improve safety, and reduce emissions (Trubia et al., 2020).

Tests for upper automation-level vehicles reveal that autonomous vehicles' correct and safe operation be achieved with intelligent embedded systems (Trubia et al., 2020). However, the prevalence of autonomous vehicles is low due to the legislative aspects and the low infrastructural quality of countries.

Intelligent transport can be significantly improved by introducing autonomous driving and autonomous vehicles (E.-K. Lee et al., 2016). Therefore, to train and integrate autonomous vehicles in cities and countries to achieve ubiquitous transportation and ubiquitous cities, the facilities and infrastructures in countries should be enhanced and improved.

B. *Connected Vehicles*

Vehicles can be connected in various ways, such as connecting to a navigation system or the internet. For example, using SIM cards, 5G, and IoT technology, connecting to a network of vehicles through Li-Fi communication and blockchain-secured ad-hoc vehicle networks, and so on (Bran et al., 2021). In addition, autonomous vehicles are also connected to the embedded intelligent car system (Iqbal & Rana, 2019).

On the other hand, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies enable connections between vehicles and road infrastructures, establishing networks that allow information exchange among all parties (Cai et al., 2017). For instance, V2V communication enables the synchronisation of traffic information. Moreover, vehicle-to-everything (V2X) communication technology enables connections between vehicles and other objects (Trubia et al., 2020). An example of V2X communication is connecting vehicles with roadside unit (RSU) devices to exchange data for offering valid parameters for assessing and implementing road interventions. T data can be further transferred to other vehicles and assist the vehicles in similar contexts (Trubia et al., 2020).

Vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) concepts and technologies are an effort towards ubiquitous transportation as vehicles are connected to other objects. Moreover, information exchange between the entities assures information transparency in the transportation domain. This can further benefit better traffic management and monitoring. This might also lead to reduced traffic congestion and accidents, resulting in better transport in cities and countries.

VI. Illegal Vehicle Parking Detection Systems

Illegal vehicle parking is a common problem in urban dwellings. Ubiquitous transportation concepts can be applied to curb this issue. He et al. (2018) proposed, designed, implemented, and deployed an illegal vehicle parking detection system based on trajectories of sharing bikes. The detection of illegal vehicle parking events is based on the data mining results on trajectories of sharing bikes. The system has two major modules (He et al., 2018):

A. Pre-processing

This module consists of cleaning trajectory data, map-matching GPS points to road segments and constructing indexes to accelerate the process of retrieving trajectories based on temporal ranges and identifications of road segments.

B. Illegal parking detection

This module establishes a model for road segments to determine the average trajectories, extract features from evaluation trajectories, and detect illegal parking events through distribution tests.

He et al. (2018) deployed the system on a cloud platform, Apache Sto. In addition, they used the system internally by performing great experiments on a large dataset to evaluate the effectiveness and efficiency of the system. The results of the evaluations indicate that the system performs better than other baseline methods.

Feasibility of the System, Although the illegal vehicle parking detection method, is novel, some criteria and challenges affect the system's feasibility (Zhang et. al., 2022).

First, the system cannot provide genuinely accurate results as the detection results are only based on sharing bike trajectories. Although a model is built and average trajectories are identified, the system can still produce false-negative results when abnormal events occur at the road segments. For example, car accidents, obstacles such as a tree fall, road maintenance works, roadblocks, etc. These events will result in abnormal trajectories of sharing bikes as riders will cross the road segments differently from the average trajectories to bypass the affected areas on the road segments. This will then result in the false detection of illegal vehicle parking events.

Moreover, the system can only detect possible illegal vehicle parking events, while the system cannot impose punishments for the events. Therefore, the need for traditional methods like police patrols is not eliminated to punish users who park their vehicles illegally. In other words, the system can be used as an assistive tool to detect illegal vehicle parking events but the punishments for the events still need to be done through the conventional approaches.

Furthermore, the system is only feasible if sharing bikes are widely used in the detection area of the system. If the usage of sharing bikes is low in an area, the system's accuracy will be relatively low too.

Additionally, companies that provide sharing bikes may vary by area or country. Many efforts are still needed for the system to be globalised, such as collecting and integrating information from different bike-sharing systems or companies.

Despite the mentioned criteria and challenges, the illegal vehicle parking detection system is a ubiquitous approach that implements trajectory data and mining. Moreover, it offers a lower cost and more excellent coverage of illegal vehicle parking detection compared to conventional detection approaches such as police patrols and surveillance cameras.

The system can be further improved and enhanced in multiple aspects. For instance, enhance the system so that it can differentiate illegal vehicle parking events from other abnormal or temporary events on the road segments. However, the system's feasibility is still low as sharing bikes is not widely used in all countries and areas.

VII. Conclusion

The research paper discussed several applications of ubiquitous computing in the transportation domain. The applications' uses, impacts, and feasibilities are also critically examined. GPS is a successful and widespread application of ubiquitous computing that enables services in the transportation domain and adds services to other domains. Ubiquitous computing is also applied in the public transportation environment to offer better passenger services, increasing the attractiveness of public transportation. Besides, the concepts and introduction of autonomous and connected vehicles are keys to ubiquitous transportation and cities. On the other hand, the studied illegal vehicle parking detection system requires enhancements to be more feasible.

In a nutshell, ubiquitous computing and ubiquitous cities are the upcoming trends. People will become less aware of interacting with computational infrastructures as computing technologies are integrated seamlessly into physical objects. There are already applications of ubiquitous computing in the transportation domain, but ubiquitous transportation is still relatively new as most concepts and applications are not mature. Therefore, efforts are needed to enhance and develop new applications in the transportation domain. Moreover, improvements in facilities and infrastructures are also required to integrate the applications into cities and countries to achieve the goal of "ubiquitous".

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