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An Outdoor Navigation Assistance System for Visually Impaired People in Public Transportation

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ABSTRACT Visually impaired and blind people (VIBP) have to face significant difficulties locating public transport vehicles and bus stops due to their vision restrictions. Over the past decade, diverse assistance systems have been developed to solve this problem. However, most of them are based upon the global positioning system (GPS) and present satellite coverage problems in indoor environments. Some others are wearable prototypes that turn out to be onerous for the user. This paper presents an assistance system for VIBP in the use of public transportation. The proposed system uses Bluetooth Low Energy (BLE) technology for location and communication purposes, and a mobile application for user-smartphone interaction. The BLE beacons are installed on buses and their stops; accordingly, the mobile application tracks them in real-time and provides the relevant information to the user employing verbal instructions; transportation line, destination, next stop name, and current location. This information allows the user to properly select the desired bus in advance and get off at the correct destination stop. The proposed system has been tested in two scenarios: 1) under controlled conditions and 2) in a real environment. The results show that the proposed system is 97.6% effective when VIBP travel independently from one point to another. In addition, according to an assessment sheet completed by the participants, the proposed system grants them greater confidence and independence than GPS-based systems because of the following reasons; firstly, it can work with an internet connection or without an internet connection. Secondly, it is not an onerous system; information about the location of vehicles and stops is provided in real-time. Last but not least, it does not present satellite coverage problems in indoor environments.

INDEX TERMS Assistive technology, visually impaired people, partially sighted passenger, mobile application, public transport, Bluetooth low energy technology.

I. INTRODUCTION

Visually impaired and blind people (VIBP) face diverse challenges in their daily lives, one of the most important commuting by public transport. Currently, many cities operate with public transport management systems (PTMS). Such systems help to increase the efficiency of transport vehicles, reducing travel times and improving punctuality. On a general basis, PTMS provides information about estimated arrivals and departure times, and travel times. Usually, such data are displayed on designated digital screens located within bus stops. However, that is very useful for almost all passengers, but it is entirely useless for VIBP due to their disability. Over the past ten years, diverse systems have been developed to

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help VIBP in the use of public transport [1]–[5]; nevertheless, their functionality depends on a constant internet connection, the majority of which is based on the global positioning system (GPS) which present satellite coverage problems in indoor environments. In addition, they are wearable and onerous devices that affect the natural movements of the user.

In this paper, an outdoor navigation assistance system based on Bluetooth Low Energy (BLE) technology and the development of a mobile application for VIBP in public transportation are presented. It consists of BLE beacons installed in the public transport vehicles and bus stops which are tracked by the mobile application that enables user-smartphone interaction. Feedback is provided to the user through verbal instructions. The proposed system has been tested in two scenarios: (1) under controlled conditions and (2) in a real environment. In both cases, the results show that the proposed system is 97.6% effective when VIBP travels from one point to another. In this regard, they can board the desired transport vehicle and get off at the desired bus stop independently. After implementing the proposed system, all participants completed an assessment sheet where they declared they feel more comfortable and secure with the proposed systems than GPS-based systems because of the following reasons: (1) it does not present satellite coverage problems in indoor environments, (2) it is not an onerous system, (3) it can work with an internet connection or without internet connection, and (4) the information about the location of vehicles and stops is provided in real-time.

The paper is organized as follows: Section II presents the state-of-the-art of VIBP indoor and outdoor navigation. Section III presents the system description. Section IV presents the validation experiments and system recognition, which were carried out in a university under controlled conditions. Section V presents the system in outdoor navigation through successfully validation experiments carried out in a city in a real environment. In Section VI, the experimental results and discussion are presented. Finally, in Section VII, some conclusions are drawn.

II. RELATED WORK

Navigational assistive systems for VIBP are divided into two parts: (1) indoor navigation and (2) outdoor navigation. Recent works developed for indoor navigation include devices that work with video cameras and image sensors combined with artificial vision techniques. These works are intended to help the user to travel avoiding obstacles, finding objects, recognizing people, among others [6]–[15], i. e., Li*et al*. [7] developed a system for indoor navigation which detects moving obstacles and adjusts route planning in real-time to improve navigation safety. On the other hand, Aakash Krishna *et al*. [10] used a vision system with a 3-dimensional (3D) audio mechanism as feedback for indoor navigation for the visually impaired. Mekhalfi *et al*. [12] implemented diverse, intelligent technologies in an assistance system with coverage in indoor navigation and the recognition of several objects in real-time; the methodology is based on laser sensors, digital camera, and MIU sensor; feedback is provided through verbal instructions. Pham *et al.* in [14] presented a deep learning-based fake-banknote detection method for the VIBP, for the development, in which they used visible-light images captured by smartphone cameras. The previous works have contributed to VIBP assistance in indoor navigation. Nevertheless, these solutions are focused on a specific vision problem. In general, as it is mentioned in [16], it is not very easy to design a general-purpose solution for human vision substitution.

On the other hand, the majority of works focused on outdoor navigation are GPS-based systems; others are on the internet of things (IoT), artificial vision, inertial sensors, and a digital camera integrated into smartphones [5], [17]–[25]. Lima *et al*. in [5] developed a mobile application that allows users to walk from one landmark to another, which provides them assistance in using public transport. It is based on GPS. Chang *et al.* in [23] developed a wearable assistive system based on artificial intelligence (AI) for blind people to safely use marked crosswalks or zebra crossings. Also, Kumar *et al.* [17] developed an IoT-based navigation assistance system for blind people; the operation consists of the use of a digital camera, a Raspberry Pi card, and ultrasonic sensors that provide information to the user about the obstacles approaching during navigation, the user receives the information through verbal instructions. Meanwhile, Croce *et al*. in [18] developed a system that allows the visually impaired to navigate unfamiliar indoor and outdoor environments; landmarks are placed to help users locate predefined paths, inertial sensors, and the integrated camera of the smartphone were used in this work. Accordingly, Gamal *et al*. in [19] presented an assistance system for visually impaired people when navigating in unknown outdoor spaces; they used a deep-learning method to give the user-independent mobility. El-Taher *et al.* in [24] presented a systematic analysis of the recently developed systems for urban navigation of visually impaired people. For his part, Chaudary *et al.* in [25] presented a teleguidance-based navigation assistance system for the blind and the visually impaired. It is based on a smartphone camera attached to their chest and uses this video to guide them through indoor and outdoor navigation scenarios using a combination of haptic and voice-based communication.

The works mentioned previously help people with visual disabilities in outdoor navigation. However, most of them need a constant internet connection for their operation, and they are wearable and onerous systems which represent a challenge for the users because they have to navigate with additional and significant weight and volume.

BLE technology has been used in recent years in diverse areas [26]–[31]; this technology has shown to be suitable for devices that require a long battery life rather than high-speed data transfer [28]. The main benefit of this approach is to achieve simpler, lower cost, and lower power consumption wireless devices [32]. Daniş and Cemgil in [26] used BLE beacons for locating and tracking moving objects in indoor environments. For their part, Baronti *et al*. in [27] presented a new database with BLE to evaluate different indoor positioning and navigation applications, which they call the location, monitoring, occupation and social interaction. Another similar work is presented by Malekzadeh *et al*. in [29], where they propose using BLE technology with Kalman filters for tracking moving objects in indoor environments. It is based on the prediction of the area of interest where the object is located. In the previous works, BLE technology has proven to be a suitable tool to communicate the user with his environment; therefore, it can be a helpful tool to assist VIBP in using public transport.

In the last decade, diverse systems have been developed to assist VIBP in public transportation; such works focus on a specific task during the travel of the user. Sáez *et al.* in [33] presented a system called MOVIDIS, which allows VIBP users to interact with buses and stations through radio frequency (RF) modules for communication purposes. Yu *et al.* in [34] presented a new system for bus reservation service called BusMyFriend. It comprises a mobile app that provides a seamless bus reservation service and notifications through a bus telematics system. It has tactile indicators at bus stops. For his part, Shingte and Patil in [35] developed a bus alert and accident system for the blind; it consists of an accelerometer sensor and a GPS for sending the location of the user through SMS messages. Also, Nartz *et al.* in [36] used BLE technology to implement a system for ticketing services in public transportation. In addition, Sahana *et al.* in [37] presented a system called PinealEyeForBlind. This system works with ultrasonic sensors and GPS modules to assist blind people using public transport and know their current location. Lima *et al.* in [5] proposed a system for VIBP to know where they are along the way, preventing them from ringing the bell for the driver to stop independently; this system is based on a mobile application that allows users to walk to reference points. Moreover, Krainz *et al.* in [38] developed a BLE-based system to help VIBP in the identification of the right bus; it consists of BLE modules installed on the buses and a smartphone as a medium for giving messages to the user, this system only contemplates the boarding stage, and it was not tested in a real environment. The aforementioned systems have proven to be useful for VIBP when using public transportation, but it is necessary to continue investigating in the development of assistance systems which contemplates both the boarding and descent stages, they have to be not onerous systems, and must provide information in real-time.

III. SYSTEM DESCRIPTION

The assistance system is developed to help VIBP in public transportation. Its functionality is described in Fig. 1; it consists of a developed mobile application called SUBE (System for Urban transportation in Blind pEople), allowing the connection between the smartphone and BLE beacons installed in the transport vehicles and bus stops. So SUBE can track and identify the transport vehicles and bus stops and give the information to the user in real-time employing verbal instructions. The BLE beacons installed in the vehicles and bus stops emit a Bluetooth signal with a period of 3 s, the mobile application receives this signal, and the unique identifier (ID) is obtained.

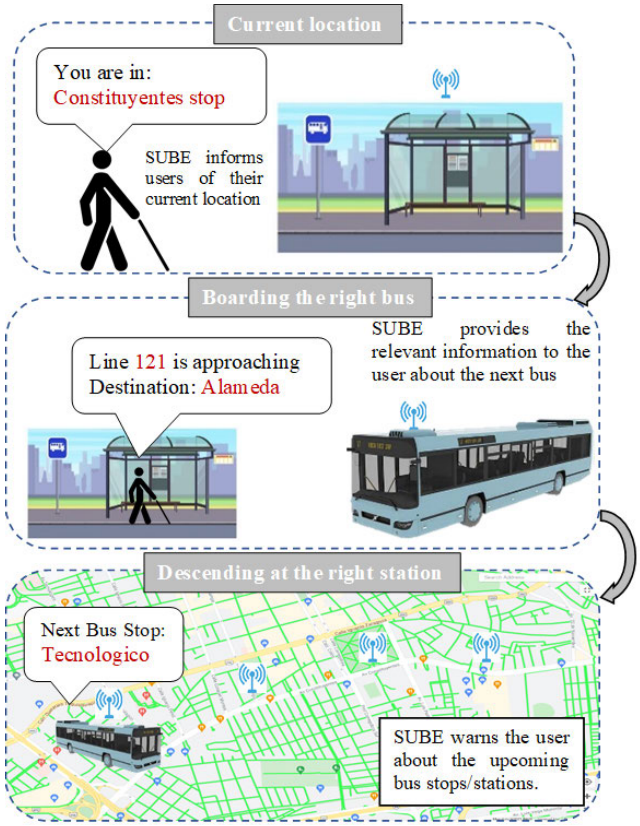


FIGURE 1. General description of the proposed system.

As shown in Fig. 1, when users arrive at a bus stop, SUBE gives them information about their current location; the users activate the vehicle tracking mode to obtain real-time information about the buses approaching their location. In this way, they can board the desired bus. When the users board the bus, SUBE gives them a confirmation message about the bus line and its destination. During the journey, the users activate the stops tracking mode, and SUBE gives them information in real-time about the bus stops they are approaching to select their destination stop well in advance. Finally, when getting off the bus, SUBE informs the user of its current location again.

Fig. 2 shows the general architecture of SUBE. Notice that it is comprised of three main buttons: vehicle tracking, bus stop tracking, and stop. When the ''Vehicle tracking'' or ''Bus stop tracking'' button is pressed, SUBE starts searching for nearby beacons; if it does not find any beacon, the users receive a verbal instruction informing them no vehicles are approaching or upcoming bus stops according to the button they have pressed, and SUBE starts searching for nearby beacons again. If it does find any beacon, the application compares the ID beacon-number with the database of bus stops or vehicles; when the ID beacon-number corresponds to the contained database information, the users receive a verbal instruction warning them that a vehicle is approaching, or they are approaching the next bus stop. Moreover, if the users press the "Stop" button, all the processes stop, and the application is closed, which means the users have arrived at their destination.

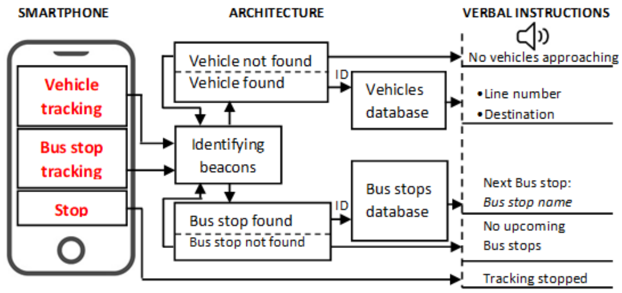
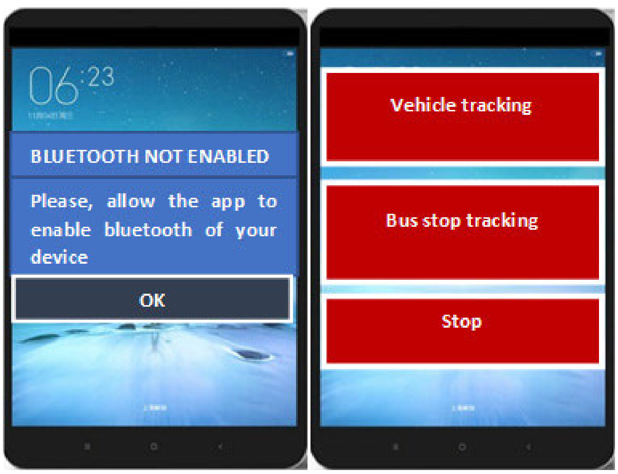


FIGURE 2. **The architecture of the mobile application SUBE.**

For the development of the user interface, it must be considered that modern smartphones contain GPS, a digital compass, accelerometers, inertial sensors, and connectivity capabilities, making them ideal candidates for portable computing applications [39]. Also, they have become an essential part of the life of VIBP, who rely on screen readers (Voiceover [40] and, Talkback [41]) to interact with the phone [42].

According to the platform, SUBE, the mobile application reported in this paper, was developed on the Android Studio©platform for the version Android©5.1 Lollipop, which can run on 92.3% of Android©devices. Fig. 3 shows the user interface of SUBE.



a) b)

FIGURE 3. **The user interface of the developed mobile application SUBE: (a) Bluetooth activation request. (b) Main menu.**

As shown in Fig. 3a, SUBE asks the users to enable the Bluetooth of their smartphone to start the vehicle or bus stops tracking on a regular trip. This information is also given to the user through voice messages.

Then the main menu is opened, as shown in Fig. 3b; it consists of three buttons mentioned before: vehicle tracking, bus stop tracking, and stop. The user interface is designed to be intuitive, easy to use and, ergonomic. Having only three buttons makes it easy to use for VIBP, and they do not waste time displaying a multiple options menu while traveling, which could lead to not boarding the right bus or not getting off at the correct stop.

IV. LOCAL TRAVELING AND SYSTEM RECOGNITION

Preliminary experiments were carried out to evaluate the performance of the system. Before testing outdoor navigation, it was first verified that the user interface could transmit discernible verbal information. The smartphones of the participants were used for experimentation; all of them run under the Android© operative system.

A. STUDY PARTICIPANTS AND EXPERIMENTAL SETUP

There were six participants for the experiment; all of them currently use or have used public transport independently in the past. Table 1 presents their description. The average age is 34.5 years old, and a standard deviation equals 12.58; their vision level is determined according to [43]. Informed consent was read to the participants before the experiment. This document specifies that they can leave the project at the time they require it. This research protocol was registered in the Ethics Committee of the Universidad Autonoma de Queretaro with the number CEAIFI-124-2019-TP regarding human tests.

During the experiment, the participants comfortably used a smartphone with the mobile application SUBE installed. General instructions about the task were comprehensively given; also, the participants used the interface for 10 minutes to get familiar with it.

TABLE 1. **Participants description.**

Number	Age	Vision level	Sex
1	54	TB	M
2	40	TB	F
3	24	LV	F
4	22	LV	M
5	26	NS	M
6	41	NS	M

M: Male, F: Female, TB: Totally blind, LV: Low vision level, NS: Normally sighted.

The tests for the boarding and descent stages were carried out separately to validate the user interface functionality. This part of the experiment was carried out under controlled conditions within the campus of the Universidad Autonoma de Queretaro in Queretaro, Mexico.

B. METHOD

Fig. 4a and 4b show the detailed circuits followed by the test vehicles during the boarding and descent stage, respectively. The distance between points: A and B is 50 m, B and C is 40 m. On the other hand, the total length of the circuit showed in Fig. 4b is 1936 m.

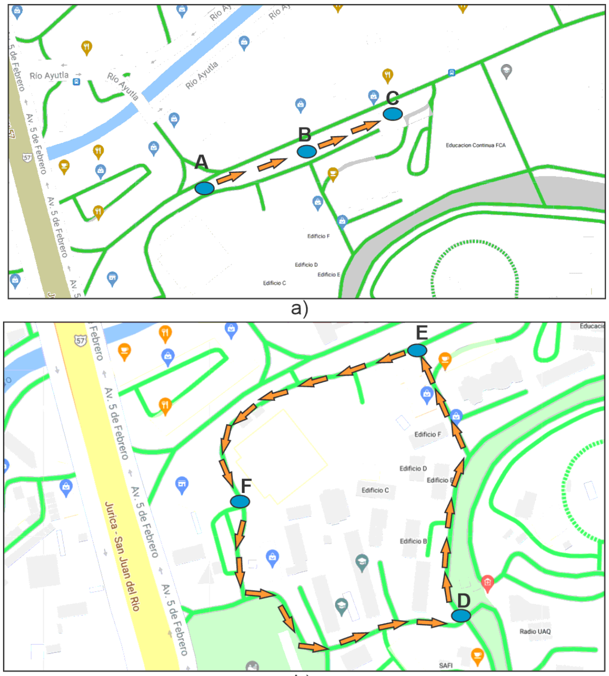


FIGURE 4. **Circuits for local traveling experimentation; (a) Boarding stage; (b) Descent stage.**

As shown in Fig. 5, two vehicles were used to experiment; a BLE beacon was installed in each vehicle, each beacon has an ID that allows SUBE to recognize them and provide the corresponding information to the participants.

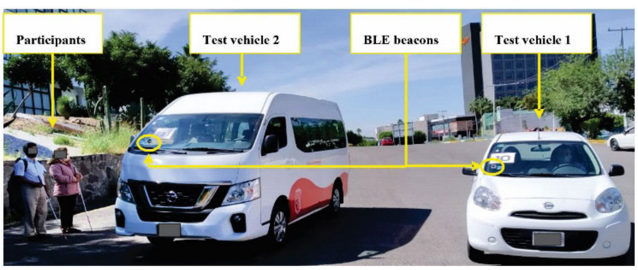


FIGURE 5. **Experimental setup for local traveling.**

In Fig. 5, Test vehicle 1 represents the unwanted bus, and Test vehicle 2 represents the desired bus. The performance parameters considered for this stage are described in Table 2.

The parameter *VS* represents the speed of the test vehicles in every test. *VD* is equal to 1 if the system detects the test vehicle and 0 if the test vehicle is not detected. *SB* is equal to 1 if the participants board the desired vehicle and 0 if they do not. *SD* is equal to 1 if the participants descent at the desired stop in point F (Fig. 4b), and it is equal to 0 if they do not get off at this point. *URT* is the remaining time the participants have before the vehicle reaches his location or the time they have to get off at the correct bus stop.

TABLE 2. **Performance parameters.**

Parameter	Description	Units
VS	Vehicle speed	km/h
VD	Vehicle or bus stop detection	0-1
SB	Successful boarding	0-1
SD	Successful descent	0-1
URT	User reaction time	s

For the boarding stage, 30 tests were carried out at five different vehicle speeds; the experiment consists of the vehicles to follow the circuit shown in Fig. 4a, the departure is from point A to point B, SUBE must recognize the coming vehicle and provide the information to the participants, the participants must decide whether to board the vehicle or wait for the next one. Finally, they arrive at point C, which represents the destination stop.

In the descent stage, 30 tests were carried out at five different speeds, and the circuit shown in Fig. 4b was used. The participants boarded on a vehicle at point D and began the travel along the entire circuit; points E and F represent bus stops. Before reaching each point, SUBE warns them that they are approaching the next stop. When the participants are approaching point E, they receive the instruction about a next stop, and they must realize it is not its destination. Finally, they arrive at point F that represents the destination stop; at this moment, they must announce to the driver that they want to get off the vehicle as if they were in a real environment.

V. OUTDOOR NAVIGATION

In this section, the experiments are carried out in a city to evaluate the system performance in a real environment, and to determine whether VIBP could successfully arrive at a destination with the assistance provided by the system.

A. STUDY PARTICIPANTS AND EXPERIMENTAL SETUP

In this stage, to guarantee the effectiveness of the system, all participants described in Table 1 performed the tests.

For the experimentation, 36 tests were carried out in the boarding stage, and 36 in the descent stage. These tests were carried out on Constituyentes Avenue at Queretaro City, Mexico; the corresponding map is shown in Fig. 6.

The points are shown in Fig. 6: G, H, I, J, and K are bus stops. The arrows that are observed in Fig. 6 represent the trajectory of the public transport buses. BLE beacons were installed at these bus stops and in the buses used for the experiment, as shown in Fig. 7. The procedure was explained to the participants: the desired transport line they must board and the destination stop where they must descend.

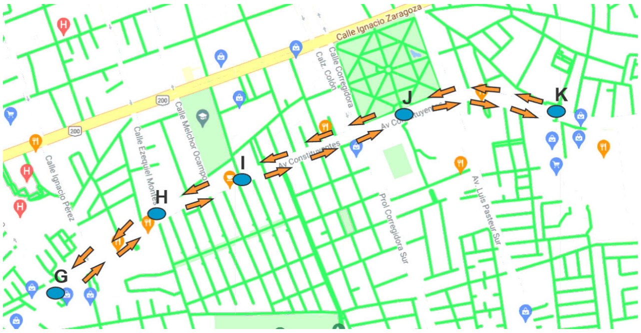


FIGURE 6. Followed circuit for the experiment.

FIGURE 7. BLE beacons installation for outdoor navigation.

The participants depart from a selected bus stop and must board on the corresponding line; finally, they must descend at another point in the city only with the assistance of the proposed system.

B. METHOD

The boarding and descent stages were carried out in the same experiment since the participants moved from one point to another within the city. The tests consist of the following: each participant starts from a selected departure stop and must identify and board the corresponding bus only with the assistance provided by the system; they must identify, and descent in the destination stop independently. Fig. 8 shows the participants receiving instructions from the system as they perform the tests.

FIGURE 8. Participants using the system during the experiment.

Table 3 shows the order of the tests, considering the departure stop, the destination stop, and the corresponding transport line for each test. The transport lines used in this experiment were 121 and 65.

TABLE 3. Order of tests.

Test	Departure stop	Destination stop	Transport line
1	J	H	121
2	H	K	65
3	K	I	121
4	I	G	121
5	G	K	65
6	K	J	121

The six participants performed the six tests described in Table 3, and the performance parameters described in Table 2 were considered for assessment purposes.

VI. RESULTS AND DISCUSSION

In this section, the local traveling and outdoor navigation results are presented. In addition, a comparison with related work is introduced, as well as an assessment sheet completed by the participants to score the proposed system in diverse aspects such as usability, ergonomics, intuitiveness of the mobile application, and a comparison with GPS-based systems is presented.

A. LOCAL TRAVELING RESULTS

These tests focused on verifying that the user interface could transmit discernible verbal information, in addition to assessing the efficiency of the system under controlled conditions.

In Table 4, it can be observed that for the boarding stage, the effectiveness percentage of the system was 100%, which means all participants selected and boarded the desired vehicle in the 30 tests performed. The participants were able to board the desired vehicle and discard the unwanted vehicle as it is observed in *SB*; the reaction time *URT* the user had to indicate the driver to stop is from 6 s to 10 s, which is enough time to board the vehicle. The *VD* parameter indicates that the system can recognize the approaching vehicles with 100% efficiency since the connection between the BLE beacons and the smartphone was successful in all the tests performed.

On the other hand, in the tests corresponding to the descent stage shown in Table 4, the average effectiveness of the system is 93.3%. The participants managed to descend the vehicle 28 of 30 times at the selected point F, which represents the destination stop. Point E, which represents the undesired stop, was detected by the system in all tests. Nevertheless, when the tests were carried out at 15 km/h, the system did not detect the destination stop on two occasions. The reaction time *URT* that the user had to make the descent at the destination stop (point F) is from 2 s to 20 s, which turns out to be enough time for the participant to get off the vehicle independently. Cells highlighted in a gray color show the tests that were not performed successfully.

The capabilities of the proposed system were verified for the boarding and descent stages. However, it is necessary to test the system in a city under real conditions and contrast it with other similar works [1], [36], [44]. Furthermore, the

TABLE 4. Local traveling results.

	Boarding stage										*Descent stage*									
	Vehicle speed																			
	5 km/h		*10 km/h*		*15 km/h*		*20 km/h*		*25 km/h*		*5 km/h*		*10 km/h*		*15 km/h*		*20 km/h*		*25 km/h*	
Participant	*SB*	*URT*	*SB*	*URT*	*SB*	*URT*	*SB*	*URT*	*SB*	*URT*	*SD*	*URT*	*SD*	*URT*	*SD*	*URT*	*SD*	*URT*	*SD*	*URT*
1	1	10	1	7	1	7	1	8	1	8	1	2	1	8	1	6	1	7	1	8
2	1	10	1	7	1	6	1	9	1	8	1	5	1	6	**0**	-	1	7	1	8
3	1	10	1	7	1	8	1	8	1	8	1	3	1	8	1	10	1	8	1	8
4	1	10	1	7	1	7	1	10	1	8	1	2	1	20	**0**	-	1	10	1	8
5	1	10	1	7	1	6	1	9	1	8	1	4	1	17	1	15	1	10	1	8
6	1	10	1	7	1	7	1	9	1	8	1	5	1	20	1	9	1	8	1	8

SB: Successful Boarding (0-1); *SD*: Successful Descent (0-1); *URT*: User Reaction Time (s)

TABLE 5. Outdoor navigation results.

	Boarding stage												*Descent stage*											
	Departure stops												*Destination stops*											
	J		H		K		I		G		K		H		K		I		G		K		J	
Participant	*SB*	*URT*	*SB*	*URT*	*SB*	*URT*	*SB*	*URT*	*SB*	*URT*	*SB*	*URT*	*SD*	*URT*	*SD*	*URT*	*SD*	*URT*	*SD*	*URT*	*SD*	*URT*	*SD*	*URT*
1	1	16	1	13	1	11	1	19	1	12	1	22	1	13	1	23	1	24	**0**	-	1	18	1	16
2	1	21	1	10	1	8	1	15	1	13	1	18	1	14	1	23	1	22	1	10	1	18	1	16
3	1	24	1	8	1	11	1	17	1	19	1	15	1	12	1	24	1	24	1	13	1	17	1	16
4	1	15	1	7	1	11	1	21	1	12	1	13	1	14	1	22	1	24	1	10	1	17	1	17
5	1	21	1	8	1	14	1	18	1	18	1	16	1	12	1	25	1	22	1	12	1	16	1	18
6	1	19	1	14	1	16	1	19	1	19	1	12	1	14	1	21	1	25	1	13	1	16	1	15

SB: Successful Boarding (0-1); *SD*: Successful Descent (0-1); *URT*: User Reaction Time (s)

participants must fill an assessment sheet to know the usability, intuitiveness, and ergonomics of the proposed system and make a comparison with similar works and GPS-based systems [21], [45], [46].

B. OUTDOOR NAVIGATION RESULTS

This section presents the experiment results in a real environment; in this case, boarding and descent stages were performed in the same test where the participants travel from one point to another within the city. Table 5 shows the results for the boarding and descent stages.

As can be seen in Table 5, all participants were able to recognize the desired bus and board it successfully in each test, with a minimum anticipation time *URT* of 7 s and a maximum of 24 s. Therefore, according to the parameter *SB* in the boarding stage, the effectiveness percentage of the system is 100%. On the other hand, regarding the descent stage, 35 out of 36 tests were carried out successfully, which gives the effectiveness of 97.2%; participant number 1 could not descend in the correct stop in test number 4, having to travel from the bus stop I to bus stop G. Cells highlighted in a gray color show the tests that were not performed successfully.

The results show that the user reaction time *URT* in the descent stage is a minimum of 10 s and a maximum of 25 s, which results to be enough time to perform the descent.

By averaging the efficiency percentages of the system in each stage, the results of the experimentation show that the system presented in this paper has total effectiveness of 97.6% and provides the information to the user with an average anticipated time of 13 s to board the bus and 14 s to get off at the desired stop. For testing the effectiveness of the system, 132 tests were carried out with six participants of different levels of vision; totally blind, low vision level, and normally sighted. First, 60 tests were carried out under controlled conditions and 72 in a real environment. The proposed system avoids some problems presented by GPS-based systems in indoor environments, such as coverage problems, stable internet connection, data inconsistency, and unknown location of the vehicle in real-time [21], [45], [46].

Additionally, the participants must fill an assessment sheet to be aware of the system performance.

C. RELATED WORK COMPARISON

This section presents a comparison of the proposed system with recent similar works.

The tasks of using public transport systems consist of multiple steps. Fig. 9 shows the journey cycle for VIBP. It was first proposed by Lafratta *et al.* [47], Soltani *et al.* [48], and Low *et al.* [49].

The journey cycle is considered in this section to compare the number of stages covered by each system.

Table 6 shows the description of the related works with which the proposed system is compared. These works were selected to be compared with the proposed system because they are recent, and their focus is very similar. It consists of assisting VIBP in the use of public transport. Table 7 shows the comparison between our proposal and recent similar works.

Tables 6 and 7 show that similar systems mostly use GPS and mobile applications, limiting indoor environments.

TABLE 6. Similar works description.

Author	Year	Components & Sensors	Feedback	Portable Prototype
Sáez *et al.*[33]	2019	RF transceivers & Embedded systems	Buzzer sound	Yes
Yu *et al.* [34]	2020	Mobile app & Tactile devices	Voice messages	No
Flores *et al.* [1]	2018	Mobile App & GPS-device	Multi-touch gesture and text-to-speech	No
Shingte *et al.* [35]	2018	MEMS Accelerometer, GPS-modules & Zigbee modules	Voice messages & buzzer alarm	Yes
Chang *et al.* [23]	2021	Camera, Accelerometer, & GPS module	Voice guidance service through earphones via Bluetooth	Yes
Krainz *et al.* [38]	2016	BLE technology & Mobile app	Voice messages	No
Lima *et al.* [5]	2018	Mobile App & GPS-device	Voice messages & vibration	No
Proposal	2021	BLE beacons & Mobile app	Voice messages	No

TABLE 7. Comparison with similar works.

Author	It can work day & night	Indoor & outdoor coverage	Journey-cycle stages	Real-time information	Tested in a real environment	Accuracy %
Sáez *et al.*[33]	Both	Both	2	✓	✗	100
Yu *et al.* [34]	Both	Outdoor	3	✗	✗	NR
Flores *et al.* [1]	Both	Outdoor	3	✗	✗	NR
Shingte *et al.* [35]	Both	Outdoor	2	✗	✗	NR
Chang *et al.* [23]	Both	Outdoor	1	✗	✓	90
Krainz *et al.* [38]	Both	Both	2	✓	✗	NR
Lima *et al.* [5]	Day	Outdoor	2	✗	✗	NR
Proposal	Both	Both	6	✓	✓	97.6

NR: Not Reported

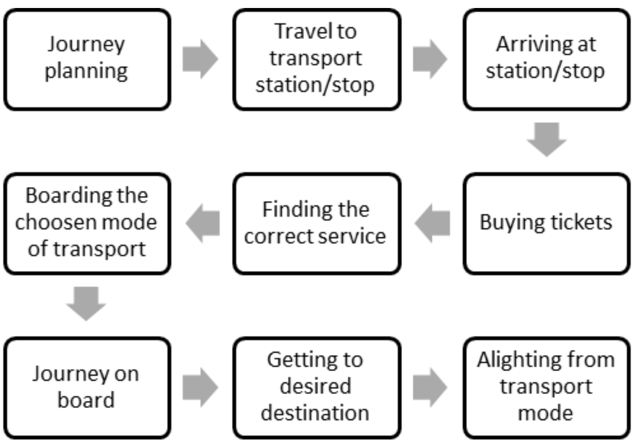


FIGURE 9. Journey cycle on public transport for VIBP (Proposed by Low *et al.* [49], Lafratta *et al.* [47], and Soltani *et al.* [48]).

Furthermore, some are wearable and onerous devices for the user, and only two of them can provide information in real-time. The proposed system can work with the same efficiency day and night and has coverage in indoor and outdoor environments; it covers six of the nine stages of the journey cycle on public transport for VIBP; arriving at the stop, finding the correct service, boarding the chosen mode of transport, journey on board, getting to the desired stop, and alighting from transport mode. Other similar systems cover a maximum of three stages. The proposed system provides information to the user in real-time.

The most similar work described in Tables 6 and 7 is Krainz *et al.* [38]. This system also uses a smartphone and BLE beacons for helping VIBP in the use of public transportation. Nevertheless, it was not tested in a real environment, and the efficiency of the system was not reported. As shown in Table 7, most of the similar works were not tested under real conditions. Sáez *et al.* [33] reported an accuracy of 100% in the RF communication success rate with different vehicle speeds, but this system was not tested in a real environment.

D. USABILITY OF THE SYSTEM

Once the participants have concluded the experimentation stage, they filled up an assessment sheet to detect the extent of adaptation they acquired with the system in diverse aspects: usability, ergonomics, and intuitiveness of the mobile application. Table 8 shows the results of the assessment sheet of

TABLE 8. System usability.

No.	Statement	Rating
1	*The mobile app is intuitive*	5
2	*Provides discernible information*	4
3	*User-phone interaction is achieved*	4.5
4	*It takes not contemplated actions*	1
5	*You can use the system autonomously*	5
6	*It is reliable*	5
7	*It is consistent*	5
8	*It is onerous*	1
9	*It is concise*	5
10	*Provides the information on time*	4

Rating: 1 = "I strongly disagree", 2 = "I disagree", 3 = "I partly agree", 4 = "I agree", 5 = "I strongly agree"[50]

the proposed system rated according to the Likert scale [50] to make a quantitative analysis of the participant's opinion. The statements described in Tables 8 and 9 are focused on the proposed system.

As observed in Table 8, all participants fully agreed that the system SUBE is easy to use and very intuitive; they all agree that the system grants them greater confidence and independence. Additionally, they mentioned that the system is consistent since the information is provided in the same way for each vehicle or bus stop. On the other hand, all the participants mentioned that the system does not perform unanticipated actions, and the information is provided sufficiently in advance.

E. COMPARISON OF THE PROPOSED SYSTEM AND GPS-BASED SYSTEMS

All participants declared they have used a GPS-based traveling assistance system before this experiment; in this regard, an assessment sheet is filled to compare the proposed system and the commonly used GPS-based systems. Table 9 shows the average of the responses of the participants.

Table 9 concluded that the system reported in this paper is advantageous compared to GPS-based systems. All participants declared that the proposed system provides greater confidence because it can work with or without an internet connection, and it does not present coverage problems in indoor environments. They also mentioned that it is easier to use because they only have to handle three buttons: vehicle tracking, bus stop tracking, and stop. The system only provides the necessary information: line number, destination, next stop, and current location. All participants fully agreed that the system gives them greater independence in using public transport, and this system represents a viable option to help people with visual disabilities in public transport services.

This work contributes to a flexible smart city that adapts the needs of its people through data analysis and the implementation of new technologies [51].

TABLE 9. Comparison between the proposed system and GPS-based systems.

No.	Statement	Rating
1	*It is easier to start the application*	4.5
2	*The mobile application is intuitive*	4.5
3	*Information provided is accurate*	4
4	*Information is delivered in a timelier manner*	4
5	*It is reliable because it does not present coverage problems in indoor environments*	5
6	*It is reliable because it can work with or without an internet connection*	5
7	*The user interface is easier to use*	5
8	*It gives greater independence in traveling*	4.5
9	*It is reliable because the information is provided in real-time*	5
10	*It is concise because it only provides the necessary information*	4
11	*Having only three buttons makes the app easier to use*	5
12	*It takes less time to load the information*	5

Rating: 1 = "I strongly disagree", 2 = "I disagree", 3 = "I partly agree", 4 = "I agree", 5 = "I strongly agree" [50]

VII. CONCLUSION

This paper presents the development of an assistance system to help VIBP in the use of public transport. It was tested under controlled conditions and in a real environment.

The results of the tests performed under controlled conditions show that the user can recognize the instructions provided by the system. The participants were also able to independently board a selected vehicle and get off at the assigned destination stop. On the other hand, the results of the tests carried out in a real environment show that the participants can travel from one point to another within the city independently only with the assistance of the proposed system.

A comparison with recent similar works shows that the proposed system covers six of the nine stages of the VIBP journey cycle, while the other systems cover a maximum of three stages. Additionally, an assessment sheet filled by the participants after the experiment shows that the system is consistent, reliable, the user interface of the application is intuitive, and it is not onerous. Furthermore, a comparison with GPS-based systems shows that the proposed system is advantageous in indoor environments because of the following reasons: it does not present coverage problems in indoor environments, it can work with or without an internet connection, and information about the location of vehicles and stops is provided in real-time.

The proposed system is a viable option for blind and visually impaired people to have access to public transport services; this approach contributes to the development of an intelligent city that adapts to the needs of the inhabitants, uses technology and data to increase efficiency, sustainability, and the quality of life of citizens.

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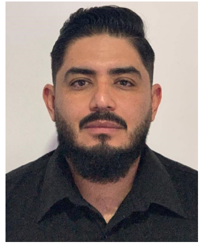

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