Universal design – Bluetooth Low Energy-based navigation information systems for people with disabilities

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The Universal Design aims to improve the functionality and accessibility of urbanized areas for all users. Bluetooth Low Energy based navigation information systems support this goal by assisting citizens with disabilities in the use of public facilities. The Article sets out the possibilities and limitations of two information navigation systems: GuideBeacon and Totupoint in supporting the spatial orientation of people with disabilities.

Introduction

Universal Design aims to support the inclusiveness of people with disabilities. The Convention on the Rights of Persons with Disabilities [1] adopted by the Assembly General of the United Nations is a legal act ratified by the Polish government in 2012, that obligates to provide people with disabilities equal access to public spaces, transport, technology, and information. Striving to achieve the Convention goals Republic of Poland launched the program "Availability Plus" [2], as a result of which in July 2019 "Act on ensuring accessibility to the people with special needs" [3] entered into life. Polish Building law [4] ensures architectural accessibility for people with disabilities while focusing mainly on users with physical dysfunctions i.e., wheelchair users. Sadly, none of the aforementioned regulations cover functional solutions that would facilitate the spatial orientation aspect of people with perception limitations.

Spatial orientation is defined by A.A. Kantarek as "the ability to recognize, establish and assessment of the situation" [5]. The ability to receive and process information from the environment which allows the human mind to develop a subjective pattern of the surrounding reality, locate himself and roam freely. People whose disability hampers this process because of physical limitations (defective or not fully functional visual system), or due to limited intellectual abilities, may need additional technological support to function independently in an urbanized space. The development of Internet technologies in recent years has allowed the creation of connections between users, computer-based devices, and the surrounding reality. This trend noticed at the beginning of the 21st century has been called the Internet of Things (IoT). The use of wireless data transfer allows people with disabilities to recognize spaces and objects in their environment, interact with them and, as a result, significantly increase the possibilities of independent functioning. This article discusses the principles of Bluetooth Low Energy (BLE) technology-based navigation devices, introduces and compares the GuideBeacon and Totupoint navigation information systems in terms of the possibilities of their operation, the scope of information provided, identification of limitations and challenges, and indication of possible development perspectives.

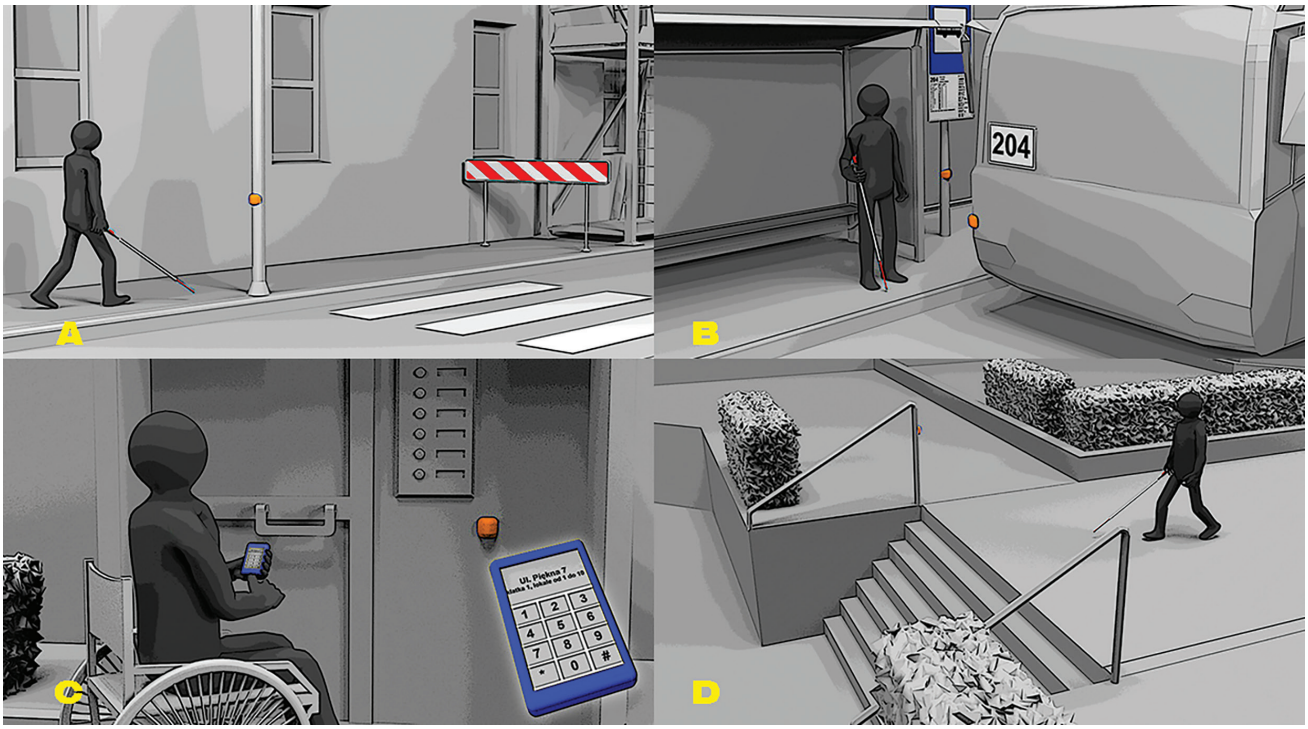
Literature Review

The study analyzed the legal conditions related to architectural accessibility for people with disabilities and the possibilities of using modern technologies to support the idea of universal design in architecture. The various possibilities of using wireless technology in service of people with disabilities, in the context of the Internet of Things idea, were included in the „An overview of the Internet of Things for people with disabilities" [6].

Information on navigation and information devices based on Bluetooth Low Energy technology is discussed extensively in the "Indoor positioning and wayfinding systems: a survey" [7] while "Beacon-based wayfinding for people with disabilities" [8] and "Beacon deployment guide: a study on Bluetooth Low Energy Beacon Infrastructure setup for indoor way-finding" [9] explain the principle of functionality of Beacon transmitters, focusing on their use in creating The Guide Beacon navigation system. The knowledge about this technology, contained in the previously-mentioned sources, will facilitate the understanding of the principles of the functionality of the Totupoint system as the scientific data on Totupoint navigation information system is difficult to obtain. Most of the information can be found on the totupoint.pl website or by listening to radio podcasts on the Internet radio Tyflopodcast [10], in which the author of navigation described the concept and basic functionality of his creation.

The aim and method of the research

The main aim of this article is to present the capabilities of Bluetooth Low Energy-based information navigation systems dedicated to people with disabilities. The study compares the possibilities of using the open-air positioning system (GPS) and Bluetooth Low Energy system in closed facilities and clarify the principles of operation of the Beacon transmitters. The result of the research is a comparative analysis of the Guide Navigation System operated by IBeaconMap and Totupoint system in terms of functionality, adaptation to the needs of people with disabilities, limitations, the scope of information provided, and the presentation of prospects for the development of systems and implementation on a large scale. The study depended on literature review, official materials provided by the producers of the systems and records of the interviews with the creators.



Wiz. 1. Visualizations of exemplary applications of Totupoint system markers. A – Marker placed on a pole near the pedestrian crossing in front of the road works. B – The marker placed at the bus stop. C – The marker placed next to the intercom. D – The marker is placed near the potentially dangerous location; source: totupoint.pl

Results

The open-air positioning system (GPS) is widely used for navigation purposes. Although its functionality might be easily disturbed or limited by structural elements or the equipment of closed facilities. The GPS functionality depends on an algorithm which is based on the relationship between the transmitter and satellites. Furthermore, the accuracy of conventional GPS is insufficient to guide people with impaired vision.

Indoor navigation systems adopted the communication technologies such as Wi-Fi, RFID, VLC, UWB, and Bluetooth. BLE technology is gaining a significant advantage in the market by providing relatively high measuring accuracy (location with an accuracy of two meters), while minimizing implementation costs and energy consumption [7].

Beacons are stamp-size devices, which send out data in regular intervals which is received by the electronic device equipped with Bluetooth technology (most commonly a standard Smartphone). When the receiver finds itself within the range of the beacon signal, the transmitter implemented message will appear on the phone screen, most often in form of an advertisement. Beacons were created for such tasks, but further research contributed to the development of navigation information systems that fulfills the needs of people with disabilities such as GuideBeacon [8], [9], [11].

The GuideBeacon navigation system assumes the location of transmitters in close range to each other to reduce the error from a lack of precision in localizing beacons by the receiver device. The advantage of the GuideBeacon system is the dedicated IBeaconMap software that allows the user to implement transmitters single-handedly in the desired location. The GuideBeacon software supports two types of schemes: a basic floor plan (for interiors) or the schematical arrangement of architectural objects (for surroundings). Smart software allows users to change navigation preferences according to the user's needs, e.g. by assistance to the nearest emergency exit in an emergency (SafeExit4All) [8].

The Totpuint navigation and information system, similarly to the standard BLE-based technology, consists of a transmitter, a signal receiver in a Smartphone or in white cane, and a dedicated Smartphone application.

The main difference that distinguishes the Totupoint system is the enrichment of the transmitter with a sound message. J. Szuster, the creator of the system, expressed the conviction in Tyflopodcast [10], that the use of navigation systems without sound transmitters by a visually impaired person is a similar experience to navigating a vehicle with blackened windows. As he noticed, following the guiding instructions due to the inaccuracy in detecting users' position by the system, may lead to inaccurate maneuver and stopping at the obstacle. The original problem is replaced by the next one: how to return to the tag or how to adjust the coordinates without knowing the current location. People with visual impairments do not have naturally sharpened other senses that counterbalance the limitations of vision. Constant work on developing the ability to recognize auditory and tactile stimuli helps people with visual disabilities orient themselves in space based on found landmarks [12]. When the transmitter and receiver are in close range, the transmitter emits data (device identification number and/or location) and a voice message that specifies its placement (e.g. the main entrance to the building). In this case, the journey starts from a very specific point, and in case of loss, the user can use the application to force the re-emission of the audio information from the starting point or a transmitter closest to his/her current location. The application allows choosing and browsing available routes at any time, allowing visually or intellectually impaired person to prepare in advance, create a mental map, and thus helps to avoid confusion after reaching the marker.

Scope of Application of Totupoint navigation information system.

The key factor influencing the multiplicity and continuous expansion of the functionalities of the presented technology is its ability to change the software without the necessity of exchanging transmitters, and thus the service can be provided anywhere in the world. Until May 2021, over half a thousand Totupoint location markers were distributed across Poland. [13]

The table describes examples of the use of Totupoint tags for supporting people with disabilities.

Table 1. Examples of the various application and functionality of Totupoint tags for supporting people with disabilities

Application of transmitters in urbanized areas	Type of support for people with disabilities	Totupoint tags in Poland, exemplary location
State departments	Basic information on the work of the office available in the application on the phone - text, audio and sign language Possibility of mapping a route to a specific room with a voice description containing information for the blind person (only the target marker activates)	Skierniewice City Hall District Court, Kozienice Social Welfare Center in Łódź Road and Transport Authority, Łódź
Educational institutions and libraries	Navigation around the campus and inside the facilities Access to security information Possibility to call and operate the elevator via the app Use of tags in work with a student with special needsw	Lodz University of Technology, campus A, Łódź Special School and Educational Center in Chorzów Library of the Kazimierz Wielki University in Bydgoszcz
Healthcare facilities	Possibility to locate the patient The physician can have full access to the patient's health information (transmitter near patiens' bed) Possibility to call a healthcare worker by patient	Municipal Medical Center - all facilities, Łódź Hospital No. 4, Gliwice
Cultural facilities	Audio description of works of art - narrative descriptions of paintings and sculptures Audio description of museum spaces - descriptions of architecture, interior design and exhibits Exhibition related games for people with disabilities	Art Gallery of the Łódź Sejmik of Disabled People, Łódź „Syrena" Theater, Warsaw City Museum in Tychy Planetarium, EC1, Łódź
External areas	Warning messages markers- e.g. roadworks Signaling messages markers, e.g. at traffic lights Tourist information Automatic access to timetables of vehicles serving the bus stop equipped with a marker and the ability to automatically inform the driver of the vehicle about the presence of a person with special needs at the stop Information about the number of the public transport vehicle approaching the stop	Pedestrian crossing, Siemanowicka 101, Chorzów Łódź Fabryczna Bus Station, Łódź Piotrkowska Centrum tram stop, Łódź
Service facilities	The possibility of choosing a route to a specific point / store / shelf with goods, without activating the sound signals of the other markers Access to the restaurant menu via the app Information about services and promotions	„Morena" shopping mall Schouberta 102a, Gdańsk „Theater Bar" beanery, 12 Tadeusza Kościuszki Street, Gliwice „Fragrant bookstore", Bankowa1, Gliwice
Residential facilities	Easy location of entrances The possibility of using the intercom through the smartphone application - a convenience for people with visual and physical impairments	Residential development „Bocianek", Gałczyńskiego 6, Katowice Apartment block, Osiedle kosmonautów 4, Poznań
All of the above	Navigation that allows to create a route tailored to needs of a user with mobility difficulties Audio description navigation adapted to the needs of a visually impaired users Information about hazards and emergency exits Automatic evacuation navigation in an emergency, adapted to the needs of people with disabilities and informing emergency services about endangered people with disabilities	

Comparative analysis

The main features of the Guide Beacon Navigation system and Totupoint system are summarized in Table 2, which shows that both solutions have their advantages and disadvantages. Both systems are based on BLE technology, require the use of transmitters, and can be accessed by a user through a smartphone application, the Totupoint system additionally allows the use of an Activator placed in a white cane, which shakes discreetly in the presence of the transmitter. Guide Navigation System may turn out safer in large-scale facilities thanks to the ability to edit variables in real-time, by the facility management with access to IBeaconMap software. This function allows the system to immediately calculate the safest route and change it in the sudden appearance of hazard or architectural barrier. On the other hand, Totupoint systems sound signal may prove crucial in the event of a user's panic. The Totupoit system, thanks to the use of speakers in transmitters, simplifies user localization in space. The undoubted advantage of the Totupoint system is an enormous range of possible applications for supporting persons challenged in various ways.

Conclusions

Universal design aims to provide access to architectural facilities and urbanized spaces to all citizens, regardless of their physical or intellectual abilities. Technological progress and the prevalence of modern mobile devices allow the development and implementation of navigation and information systems that fulfill the special needs of people with cognitive and physical disabilities. Navigation systems based on Bluetooth Low Energy technology, thanks to a wide range of applications, versatility, and low implementation costs, will significantly improve the functionality of urbanized areas for BVI (blind and visually impaired) and BVID (Blind and visually impaired and disoriented) citizens. Both information navigation systems analyzed in the article bode well for the future, thanks to the possibility of the software evolution and involvement of creators. The authors point to the need for more research with disabled users to tailor software to the specific needs of this group.

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Table 2. Key characteristics of GuideBeacon and Totupoint navigation information systems

	Navigation and Information system	
	The GuideBeacon	Totupoint
Base technology	Bluetooth Low Energy	
Transmitters	Beacons - a very large amount is required, densely distributed in the facility	Beacons paired with speakers, located only in key locations
Receivers (required from the user)	Smartphone	Smartphone and/or activator that might be located in the white cane
The possibility of self-implementation of the system by the user.	The user implements the system using dedicated IBeaconMap software	None. The provider implements system
User guidance method	The user while entering the building uses a Smartphone app to receive the voice information about location and choose the desired destination. The system uses a map of the location to calculate the most suitable path. The user receive voice commands to move around	The user activates Beacon using Smartphone or Activator in the white cane. Transmitter with speaker emits voice message, so the user can localize the Beacon using echolocation. User chooses the next destination at the dedicated app or listens to the voice commands emitted by the transmitters' speakers
The emergency evacuation guidance	The system calculates the best safe path towards the exit, the variables might be implemented to the system in real-time. There might be a problem with locating oneself and the position of the transmitter while the user is in panic	The app has the emergency option which gives the voice commands on the best safe path towards the exit. Can't be changed without the intervention of the provider. The user might echolocate the position of the transmitter, so the starting point of the designated path is precise and can be found even in panic
Other applications	Applies to navigate inside the building and in its close surroundings, therefore might be applied to the building complex	Various ways of implementation such as providing information about the facility, menu at restaurants, turist information, audio description at museums and many more (listed in Table 1.)

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Abstract: The Universal Design aims to improve the functionality and accessibility of urbanized areas for all users, regardless of their physical, perceptual, or intellectual capability. This task is also a priority for the Polish government, however legislations do not provide clear solutions for supporting people with perceptual limitations. Contemporary technologies can support the spatial orientation of people with disabilities, allowing them to get around independently and safely. Bluetooth Low Energy (BLE) technology, unlike to the global positioning system (GPS), allows accurate indoor location and navigation. The purpose of this article is to discuss and benchmark two BLE-based navigation and information systems: The GuideBeacon supported by the IBeaconMap software and Totupoint. The result is a summary of the key functionality and limitations of both solutions and an indication of the prospects for further development.

Keywords: universal design, architectural accessibility, navigation, Bluetooth, IoT

Streszczenie: PROJEKTOWANIE UNIWERSALNE – SYSTEMY NAWIGACYJNO-INFORMACYJNE OPARTE NA TECHNOLOGII BLUETOOTH LOW ENERGY, PRZEZNACZONE DLA OSÓB Z NIEPEŁNOSPRAWNOŚCIAMI. Projektowanie uniwersalne stawia sobie za cel zwiększenie funkcjonalności i dostępności przestrzeni zurbanizowanych dla wszystkich użytkowników, bez względu na ich percepcyjne, fizyczne czy psychiczne zdolności. To zadanie jest również priorytetem działań polskiego rządu, jednakże istniejące akty prawne nie określają rozwiązań funkcjonalnych, które sprzyjałyby orientacji przestrzennej osób z ograniczeniami w zakresie percepcji. Rozwiązania współczesnej technologii mogą wspierać orientację przestrzenną osób z niepełnosprawnościami, dzięki czemu będą one mogły przemieszczać się niezależnie i bezpiecznie. Technologia Bluetooth Low Energy (BLE), w przeciwieństwie do Globalnego Systemu Pozycjonowania (GPS), pozwala na dokładne lokalizowanie oraz nawigowanie w obiektach zamkniętych. Celem artykułu jest omówienie i analiza porównawcza dwóch systemów nawigacyjno-informacyjnych opartych na technologii BLE: The GuideBeacon wspieranego przez oprogramowanie IBeaconMap oraz systemu Totupoint. Rezultatem jest zestawienie najważniejszych funkcjonalności, a także ograniczeń obydwu rozwiązań i wskazanie perspektyw dalszego rozwoju.

Słowa kluczowe: projektowanie uniwersalne, dostępność architektoniczna, systemy nawigacyjne, Bluetooth, IoT

This article has been completed while the second Author was the Doctoral Candidate in the Interdisciplinary Doctoral School at the Lodz University of Technology.