Supporting the Audial Discovering of Space by the Blind using an Ontology-based Map and Geographic Data from Existing Open Maps

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In everyday life, we often encounter a situation when we want to go to a new place. In this case, we reach for one of the internet maps services, enter data about our trip and search for a new route. It is similar in the case of blind or visually impaired people (BVE). Getting to know the new route is even more essential for them because they will be able to avoid dangerous places during the travel. Unfortunately, the information taken from various dedicated GPS-based mobile applications is usually insufficient for this purpose. They need a more exact description of an environment and objects such as pedestrian crossings or entrances to shops. To enable this detailed exploration, we propose a method that consists of assigning a new route, describing it with the use of objects and assigning text descriptions and sound patterns to them. For this purpose, we use a dedicated domain ontology. Due to this, apart from the attributes such as coordinates and size, the objects have the attributes that store the appropriate exact physical location and other semantic data such as relations to other objects. With this solution, it is possible to construct very precise descriptions of routes tailored to the specific requirements of BVE. Our concept has been implemented as a simple application that uses ontology, data downloaded from the Open Street Map and audio samples recorded with the binaural sound method.

Keywords: Blind traveller, Object map, Ontology, Sound description of space, Finding the Routes.

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1 Introduction

According to the WHO report [1], about 45 million blind people live in the world. Another 269 million are individuals with various visual disturbances. Moreover, "Lancet Global Health" predicts in its report that by 2050 the number of BVE will reach 115 million individuals. Therefore, developing new solutions for this group of users is a very important issue.

While travelling along known routes is generally not a big deal for able-bodied, hence overcoming unknown routes, especially for the blind, is associated with much stress and the necessity to prepare for undertaking them. In such a situation, the sighted person usually gets to know the new route on some website, e.g., Google maps or even conducts a more detailed explanation of this using functions such as Street View. In this case, a BVE has a much more difficult task. She/he cannot see crucial points on a route, e.g., monuments, fountains, crossings and others. Despite the existence of commercial navigation systems dedicated to the blind, such as Dot Walker [2], Lazarillo [3], Seeing Assistant move [4], or GetThere [5]. Another approach consists of installing talking points in different places in the city. Then users can recognize them using a special application running on a smartphone [6]. There are also applications based on cameras and laser sensors [7], which usually need to build a separate dedicated device or equip a white cane or glasses with additional modules [8]. The usefulness of data stored in such systems, e.g., Open Street Map [9], is usually not accurate enough for the proper implementation of navigation of BVE. It needs another very crucial information, such as the location of entrances to shops, the mutual position of the lawn about the pavement and roadway, characteristic advertising poles, passing fences or even the type of material from which it is made.

To take a step towards solving this problem, we propose a solution that, to put it briefly, consists of setting routes based on data from open maps, supplementing them with additional relevant information, and playing sounds assigned to each object located on the route. These can be sounds that are obvious and recognizable to everyone, such as the sound of a fountain or a tram turning into a depot, but not only. They can also be sounds specific to a given place, such as cars driving through a hole in the road on the left side of the user or a creaking door to a local shop on the right side. Thanks to this solution, in addition to standard verbal information for the BVE whether or not she / he is moving in the right direction on a designated route, we can familiarize the user with the characteristic sounds associated with a given route. Listening to such sounds, a blind person can create a kind of imagination snapshot, e.g., an audial fingerprint of a given place in his mind.

For enabling this feature, information about objects on the route and even the routes themselves are saved in the object map ontology specially created for this purpose. This ontology allows for describing the various parameters of these objects and relations between them. Examples of these relations can be: a pavement is a neighbour of a road or bus stop is located on the Pavement. Some of the crucial attributes of such objects are various types of sounds recorded using a binaural technique or generating with the help of the HRTF function [10]. It allows for automatic mapping of routes in the map through objects adjacent to each other, e.g., pavement1 is the neighbour of a pedestrian crossing_1, and a pedestrian crossing_1 is a neighbour of pavement_2. Passing through all objects of a given route, we can play all the sounds associated with subsequent objects. Of course, the only audio snapshot is not enough to describe the route as accurately as it should be understood by a user. The sounds must be combined with voice prompts, i.e., "let stop, you are near the intersection" or "be careful out for a parked car on the right-hand side. These messages should be read to the user via a speech synthesizer while the sound scenes are played. In this way, it gives an audio 3-dimensional explanation of the route for the BVE. Due to this feature, she / he can listen to this route before actually embarking on the real town space. It can significantly reduce his stress in this situation.

The idea of determining such routes based on data from Open Street Map, assigning sounds to them, and playing them was implemented in the form of a simple prototype application. It was tested by one blind and one visually impaired user. A concept for its implementation and further development met with a positive response. In the following sections, we will present how ontology is constructed and how an application works in practice. Then we will summaries our work and will give perspectives for its future development.

2 A Concept for Storing Audio Information About Objects and Routes

Explaining the environment adequately to the needs of the BVE requires a detailed description of the objects crucial during their navigation. To increase the adequateness of this explanation and to better describe the entire routes on which the user moves, the objects should be connected by various relations. This semantic explanation of the space can be done with a specially developed domain ontology, which defines the city's elements and relationships that are important from the perspective of the blind individual. A lot of these elements, there are classes. They define types of objects of a city's infrastructure such as Pavement, Pedestrian Crossing, Stair, Lift. Some classes describe locations, i.e., their destinations labelled by post address or GPS coordinates. Other classes define locations that may be a destination in the form of a building, which has a door that can be entered (e. g., Bank, Clinic, Restaurant, School, Shop). There are also classes providing handy information essential for the safety of a blind user. They may be objects such as traffic lights, road signs, a bollard or an advertising column and even a car park cutting into the Pavement. The proposed ontology currently contains 58 classes that can be used to define any part of the city. The structure of classes is hierarchical, e.g., the Infrastructure for Pedestrians class contains classes such as Pavement, Lift, and Pedestrian Crossing. Other elements Of the City Architecture class are Bus Stop or Trash Can.

However, we should remember that classes describe city elements as properly defined abstracts. They do not define the specific objects but describe sets of their properties and purpose. For defining specific objects on the map, the individuals are used. In our case, they represent all the places or physical elements in the city whose types were defined by classes. The examples of individuals can be pavementPilsudskiego01 (the class of Pavement) – a first section of the pavement on the left side of Pilsudskiego street; or pedestrianCrossingPilsudskiego01 (the class of Pedestrian Crossing) – the first pedestrian crossing through the Pilsudskiego street at the intersection of Pilsudskiego and Wojskowa streets. When defining the city objects, we must pay special attention to those that may be an obstacle for a blind user. Individuals representing obstacles are:

- *trashCanPilsudskiego01* (the class of TrashCan) – a trash can on the pavement edge on the street side.
- *busStop01SiedlcePilsudskiego01* (the class of BusStop) – a bus stop in Siedlce city in the middle of the pavement. It can be walked around from both sides.

Some of the other objects (individuals) may be recognized by listening to these specific sounds. Such kind of object can be, for example - trafficLightPilsudskiegoWojskowa1 (class of Traffic Light) that carry information about the possibility of a safe crossing of the street. In w actual situation, this causes the user to take city points from Open Street Map System [9] or another map service. After completion, he can save them as individuals in the ontology. Except for individuals taken straight from the existing map system, there are others that caries information about different features accessible for the BVE In actual use. An example of this can be the object trafficLightArmiiKrajowej3Maja1 type of (class) Traffic Light). It informs the user about the possibility of a safe crossing of the street.

The ontology also defines two types of properties: data properties and object properties. The data properties define the types of data that can be assigned to the domain. For example, the Address class has defined data properties such as address_country_name as a string, address_building_number as an integer. In turn, data properties are binary relations between two individuals in an ontology, and they are used to define any relationship between them. In order to ensure an accurate description of the natural environment, appropriate relations have been defined, for example:

- *appliesToPedestrian*. This property is used to determine the membership city object to another object. For example, only one object of the class Traffic Light can apply to only one object of a PedestrianCrossing class.
- *hasDirectNeighbor*. This significant symmetric relationship means that two objects are adjacent neighbours to each other. e. g. when the Pilsudskiegopavement (individual) is in this relation to Armii Krajowej Pavement (individual), we can infer that Armii Krajowej Pavement must also be in relation with Pilsudskiego Pavement via the hasDirectNeighbor property. It is worth adding that this property allows us to determine the next sequenced elements of a route.
- *isLocatedOn*. This property is used to express that something is located on the route of a blind person. For example, a trash bin is located on the pavement and may be an obstacle for the user.
- *recordedInTheLocation*. This property is used to assign a sound to a specific location. For example, the sound can represent a signal that the user can listen to while crossing the street.

Any object in the ontology representing a point on the map can be assigned a sound. These sounds can make up binaural three-dimensional sound scenes that describe different routes that blind users can meet. They can be recorded from the real world or generated automatically. Moreover, there are also other components stored in the ontology as OWL data properties. They define the data types assigned to the domain (in this case, the OWL classes). For example, the Address class has data properties i.e., address_country_name (xsd:string), address_building_number (xsd:integer), etc. There are also other elements of the ontology, namely OWL object properties. There are critical components of our map because they express the binary relations established between two objects. The relevant relations such as neighbourhood relation, location relation and others have been defined in this way to provide a better and smarter description of an environment in the ontology map.

Standard text annotations provide additional information to the user, such as descriptions, safety warnings, or more detailed explanations of a given object. These labels can be read automatically by a speech synthesizer.

The standard commonly known Ontology Web Language OWL [11] was chosen as a language for expressing our ontology. The general view of classes, properties, and individuals of our ontology is presented in Fig. 1.

3 Implementation of the Solution of Assigning and Describing Routes with Audio Snapshots

A prototype simple desktop application has been implemented to realise our solution of describing places and routes using sounds. The application uses the ontology described in the previous section and data concerning the existing points of interest taken from the Open Street Map system [9]. The prototype application consists of 3 main modules: the sound map creation module, the free travel module, and the routing travel module. Each of these modules is integrated with the Open Street Map engine and uses the OWL objects repository. The primary application architecture is presented in Fig. 2.

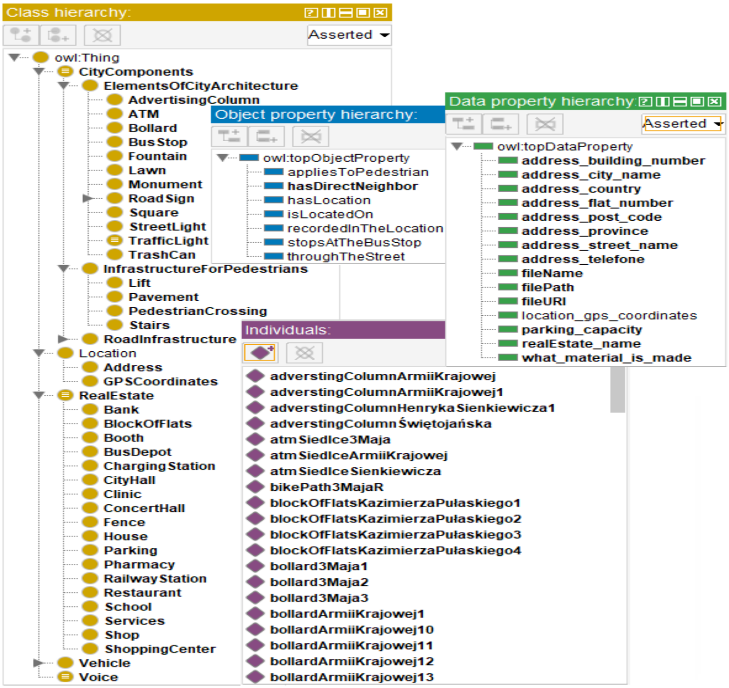

Fig. 1. Sample ontology.

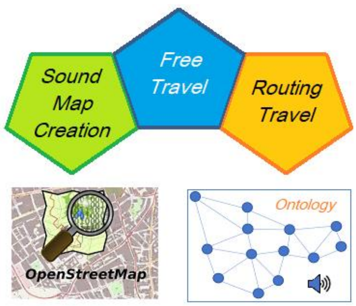

Fig. 2. Basic application architecture.

We can say that an OWL Map Creation module is a graphical interface to the OWL repository. It consists of a simple form that allows the user to expand the map with new points/objects. The form contains fields for entering the name, description, class, and geographical position in GPS format. A vital feature of this module is the ability to add sounds to a new point. Thanks to integrating this module with the Open Street Map, by adding a new point to the map, the user can faster find this point by a given phrase. The results of this search appear in the form's drop-down list. After selecting an item from this list, the new point coordinates form fields are automatically completed. The data from the form is finally persisted in the OWL repository.

Another critical part of a sample application is a Free Travel module. It allows the user to move freely on the sound map within a certain radius from a given starting point. Due to efficiency, we need the radius to load the points from the ontology file into memory. The starting point can be specified manually (by entering GPS coordinates) or searched using the Open Street Map engine. Then the user starts her / his virtual journey from the mentioned starting point. The map's navigation uses eight directional keys that the user can press with the mouse or numeric keypad. While the user is moving, the system permanently finds points in the ontology within a given (e.g., 20 m) distance from him. These points are presented graphically in a list. After selecting an item from the list, the user can listen to the sounds related to the given point.

Another part of the application is the Routing Travel module. It allows the user to create an audio route from the start point to the endpoint, near which the system searches for OWL points containing audio recordings. The route mapping takes place in two steps. In the first step, we calculate the route using the Open Street Map service. The obtained result is a list of points (p1, p2, ..., pn). Then, in the second step, for each segment (pi, pi+1), those points located at a distance not much than a predefined value (e.g., 20 meters) is searched in the OWL map.

The search is carried out according to a simple algorithm. First, we take a line connecting the two points mentioned above and determine all the sequential segments. Then, using the Pythagorean equation, we search in the ontology for all points whose distance from the PI line PI + 1 is smaller than the given one, e.g., 20m. All points matching the shorter distance criterion are added to the route. Then, the entire completed route points are sorted to create one track from the beginning to the destination. Finally, a neighbourhood relation is established between all subsequent points of such enriched route and added to the ontology. So, the final result is the OWL points list that is presented in the GUI. Each item on the list can be selected, and the sounds assigned to them can be played. In this way, the user gets to know the route by listening to all sounds accompanied to all objects sequentially. Fig. 3 shows a screenshot with a GUI of a routing travel module of the application.

4 Results and Conclusions

In this paper, we have presented a solution that gives an audio description of the environment to assist the independent navigation of the blind. This description is built as a specially created domain ontology in which individuals, classes, and relations define and describe objects from the urban environment. What is very important for a future blind user, some objects from this ontology are associated with sounds and text labels that create a virtual sound reality that acoustically describes the space. These sounds can be recorded using a binaural technique or created using acoustic filters such as the HRTF function [10]. Thanks to this, a blind user who listens to these sounds has the impression that they come to him from different directions. It is a similar impression to the actual environment where he hears various street noises.

This paper is a continuation of previous research during which the concept of ontology of an object map and its connection with binaural sound scenes was developed [12]. As part of this paper, we emphasize the ontology itself and the practical implementation realized as a prototype application. Although various algorithms support route calculation, e.g., Dijkstra [13] or the algorithms available in graph databases [14], the data from the existing GPS systems make it possible to use the route search mechanism available in them. However, because the route should be described in more detail for a visually impaired person, the points in such a route must be filtered and supplemented with additional information relevant to the users' needs. Therefore, we have implemented our method as an example prototype application. It allows the user to determine the route based on the data downloaded from Open Street Map, assign appropriate sounds to the points of this route, and then play them. As the implemented application served the first time checking of our idea, it was verified by only two blind users. This verification was to be used to check the idea itself and not the operation of the application because the functionality designed for future users will be implemented as part of a more extensive system supporting the navigation of the blind.

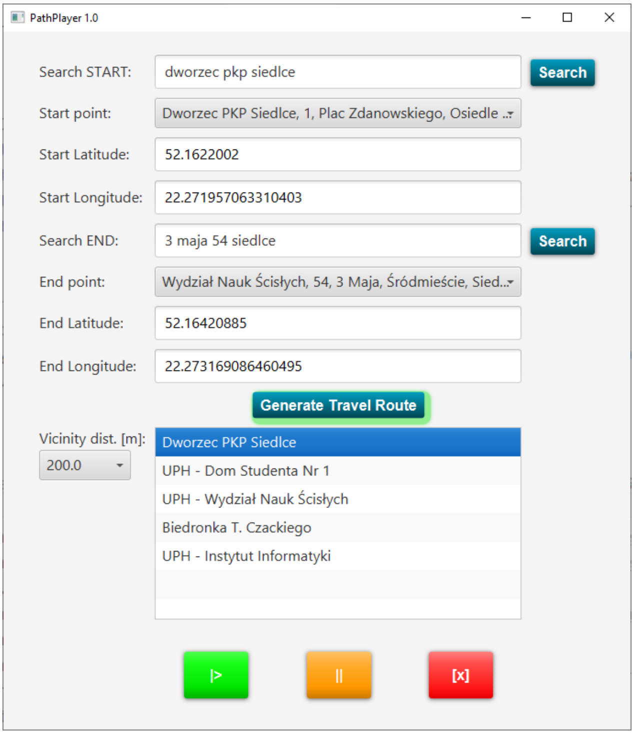

Fig. 3. Routing travel module GUI.

After testing the application, their idea met with positive feedback. However, more research is needed to adjust our method better and develop this solution in a working application. One of the possibilities of this future solution will be a mobile application supporting the navigation of the blind in the city space. We also intend to continue our research and use the object map ontology to support the navigation of the blind inside buildings. In this case, we intend to supplement it with route search mechanisms using graph databases and route guidance. In binaural sound scenes, we will have to consider different conditions at different times of the day or year in the same place. Therefore, the use of ontologies will be even more appropriate in this case.

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