Acquisition and Presentation of Diverse Spatial Context Data for Blind Navigation

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***Abstract*—In order to allow blind people independent navigation in unknown areas, we have developed a navigation system that seamlessly integrates both static maps and dynamic location-based textual information from a variety of sources. Each information source requires a different kind of acquisition technique. The acquired information is integrated by a context management platform and then presented to the user on a tactile-acoustical map depending on the sources available for his current position. Positioning is achieved by a combination of an inertial tracking system, RFID technology and GPS and the user is guided to a desired destination by speech output and a haptic cane. The resulting system is the first of its kind to integrate a variety of maps and other accumulated location-based information on a unified interface for blind people.**

I. Introduction

Navigation in an unknown environment is a difficult if not impossible task for many blind people. At the same time many of them wish to have the freedom to explore previously unknown environments just as sighted people do. A map-based navigation system can provide information about the immediate surroundings and guide the user to a chosen destination.

However, purely map-based systems are missing a lot of information the user could benefit from, such as up-to-date information on the state of the environment (e. g. defunct elevators or construction sites) or timetables of public transport. Often, the desired information can be found in the world wide web, however, the unstructured nature of the web makes it difficult to locate the specific information, especially for a blind user who is at the same time trying to navigate in an unknown environment.

We have therefore developed a navigation system that automatically integrates a number of different information sources. Several kinds of maps can be used, depending on their availability for a certain area. In addition to these maps text-based information is integrated into the system. Accordingly, the user can access all information via a tactile-acoustical map and does not need to assemble the relevant information from different sources, nor does he even need to know which information is stored fixedly in a map and which is extracted from other sources, e. g. the web. Thus, for the first time a navigation system for blind users is able to present with a single unified interface both highly detailed and large-scale maps as well as live information about the vicinity, opening up new ways of independent navigation for the target group.

The following chapter introduces related work in the area of navigation systems for blind people. In Chapter III we take a general look at navigation systems that will allow a more detailed description of the architecture of our system in Chapter IV. Chapter V takes an in-depth look at the information sources and for which purpose each source is used in our system. We follow with an application scenario presenting a possible use of the system in Chapter VI. The paper concludes with Chapter VII.

II. Related Work

Navigation systems for blind people have been a topic of research for more than 30 years now [1]. The systems that have been developed range from applications developed for a specific and well-defined purpose — like guiding a runner in a lane [2] — to full-fledged systems working indoors and/or outdoors.

Systems for outdoor use only have been existing for some time and are commercially available. These systems generally rely on GPS for positioning and use commercially available street maps to give the user feedback about his current whereabouts. However, the use of these maps restricts the applicability of these systems, as they cannot give the user detailed instructions e. g. on how to get to the entrance of a specific building. The system developed in the ODILIA project [3] tries to overcome this problem by using maps with manually inserted navigation cues. It employs commercial positioning system combining GPS and step detection and thus only works outdoors.

On the other end of the spectrum, many systems can be found that have been developed purely for indoor use. These normally rely on fixed infrastructure for positioning, such as RFID tags [4], infrared transmitters [5], [6], or modified fluorescent lamps [7].

Some systems that work both in- and outdoors use infrastructure that can also be installed outdoors, such as RFID tags [8], [9]. However, the need for infrastructure severely limits the application area, which is why other systems try to achieve indoor and outdoor applicability by using several positioning systems. Drishti combines outdoor use achieved

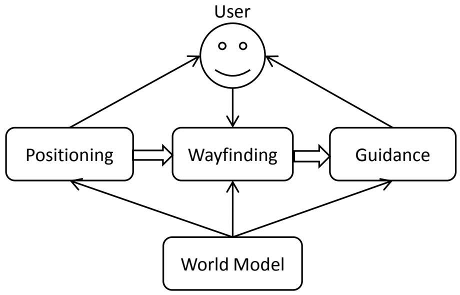


Fig. 1: **A general schema of navigation systems.** The user receives feedback about his current position, enters his desired destination and is guided to that destination.

by a differential GPS with indoor use using a commercial ultrasound positioning system [10].

All these system however face a common predicament: They are built for one specific kind of map or world model, either preexistent or specifically designed, and are not able to easily integrate additional spatial information from a wider range of sources, whereas the system presented in this paper was designed with the goal of integrating as wide a range of information sources as possible and providing a platform that allows for later addition of sources yet unthought of.

III. A GENERAL LOOK AT NAVIGATION SYSTEMS

Figure 1 shows a general schema of navigation systems. The systems are based on a world model, usually maps. These maps are then used to determine the position of the user. It should be noted that this can be understood in two different ways. On the one hand positioning can also depend on map information, e. g. car navigation systems rely on the assumption that the user travels on a road to cope with GPS inaccuracies. On the other hand, the map can be used as a lookup table for a humanly understandable feedback about the position or the immediate surroundings, while the positioning is done independently of the map. Wayfinding is also depending on maps, but needs user input, i. e. the desired destination. Guidance is the task of guiding the user to that destination after the algorithmic work has been done. Again, a map is not strictly necessary, it is possible to guide a user purely directional according to the output of the wayfinding and positioning components. However, relying on a map normally allows for context-sensitive guidance that is more intuitive for the user by mentioning features of the environment.

There are systems that are missing one or more aspects of this schema, however those are mostly designed for a specific purpose, whereas a system that aims for general applicability must encompass all of these aspects. Our system is designed according to this schema, with some additions that were necessary either due to our goal of replacing the uniform world model with a variety of sources or due to the special user group of blind people.

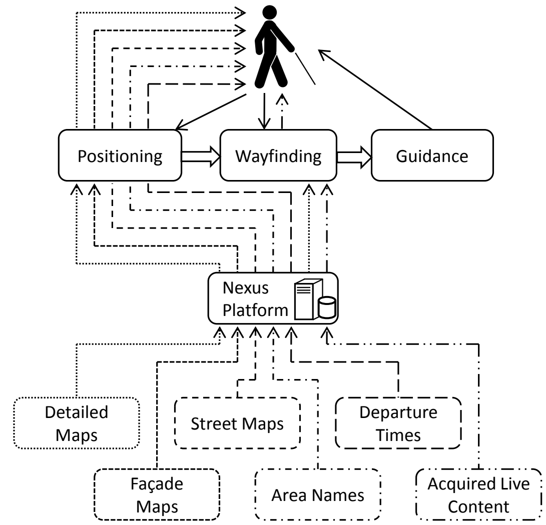


Fig. 2: **Correlation of general navigation system schema with our architecture.** The uniform world model is replaced by a variety of information sources, with differing influence on the system. The user can influence the positioining component and may receive feedback from the wayfinding component, if the acquired live content necessitates it. Detailed maps and façade maps can influence positioning by collision detection.

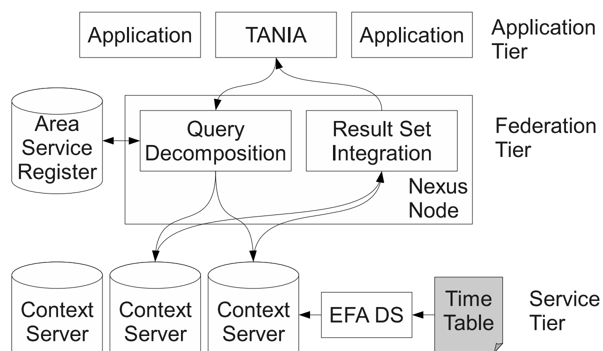


Fig. 3: **Architecture of the Nexus platform.** It consists of three tiers, the applications on the top, the systems providing data at the bottom and a federation tier in between, which distributes queries and integrates results.

IV. SYSTEM ARCHITECTURE

Figure 2 shows the architecture of our system and its correlation with the general schema presented in Figure 1. The System is based on a client-server architecture.

The world model found in the general schema is provided by the Nexus platform. It is used to integrate different information sources, which will be described in detail in Chapter V. Because of this architecture, the integration needs to happen only once and the resulting information can be used by any number of clients.

Positioning, wayfinding and guidance are handled by TANIA (Tactile-Acoustical Navigation and Information Assistant). Previous versions of the TANIA system ran as a stand-alone application [11], in the current architecture it is used as a client system communicating with the Nexus platform. Communication currently takes place via WLAN, however this could be substituted by any technology that allows for internet access of mobile devices, e. g. UMTS.

A. The Nexus Platform

The architecture of the Nexus platform [12] as used for the TANIA system is shown in Figure 3. Nexus is designed to provide general support for location-based applications like TANIA and to integrate many different sources of information relevant for such applications. The Nexus platform is a three tier system: The service tier contains the Context Servers, which actually store the data. Context Servers must provide a given interface, but their implementation is not restricted otherwise, so Context Servers can easily be tailored to specific kinds of data [13]. A Context Server hosts objects within a fixed area, which is registered at the Area Service Register (ASR). This information is used by the Nexus Nodes in the federation tier to distribute the query — based on spatial restrictions in the query — to the relevant Context Servers. Afterwards, the Nexus Node combines the result sets of the Context Servers to a single result set, which is sent to the application.

The Nexus system uses an extensible world model, the Augmented World Model (AWM) [14], [15]. The AWM consists of the Standard Class Schema (SCS) containing basic types relevant to most location-based application, and Extended Class Schemas (ECS), which can be defined by data providers or application developers. All types of the ECSs are directly or indirectly derived from types of the SCS, so that objects of types of an ECS can also be used by applications not knowing the ECS by upcasting the object. TANIA is an example for an application which profits from this extensibility. It requires a highly detailed world model containing more specific objects like furniture or pillars, which we could provide by creating an ECS for TANIA.

The AWM supports multi-attributes: An object can contain multiple instances of the same attribute. Each attribute instance can have its own set of meta-data, e. g. to represent the time frame where the value of this attribute instance is valid, so the concept of multi-attributes can be used to model varying values, e. g. the position of a car or the temperature of a room.

B. The TANIA Navigation System

The TANIA system is built of an Ultra-Mobile PC, equipped with a GPS sensor, a combined 3D compass, gyroscope and accelerometer (XSens MTx), and an RFID reader (Figure 4). The MTx is placed on a strap and positioned at the neck of the user when the device is worn.

1) Positioning: Positions inside a building are tracked by direction and accelerometer information, which is used to estimate the length of each step, by measuring vertical acceleration. As the tracking is only relative to a starting point and its accuracy deteriorates gradually, the position can be corrected at RFID tags placed at certain points in the building. As the

Fig. 4: **The TANIA navigation system.** The displayed map, acceleration sensor (on strap), rfid reader (left) and GPS receiver (top) can be seen.

range of our RFID reader is approximately one meter, the tags need to be placed at strategic positions, like doorways. Additionally, collision detection in the map is employed to further improve positioning. Positions can also be corrected by the user if he is sure of his current whereabouts. Outside, positioning can be synchronized with GPS positions, either constantly or upon request.

2) The Tactile-Acoustical Map: After the position has been determined, feedback about the surroundings can be given to the user. For this purpose TANIA features a tactile-acoustical map. The touchscreen of the UMPC is augmented with tactile strips, which indicate the map center and the four cardinal directions and help the user to orient his finger on the screen. Any map information can then be projected onto the screen, and a tap with the finger will provide the user with text-to-speech feedback about the underlying map information and the distance to his current position. Thus the user can gain a spatial impression of the environment by exploring the map. The map allows the display of hierarchically structured information, which is communicated outwards from the center. I. e. if the user taps a specific location, the system informs him about the nearest enclosing map structutre, e. g. the room number. If he taps the same location again, the system will announce increasingly larger enclosing structures, e. g. the building wing and then the building itself. To support access to the map, we provide two modes: The virtual and the navigation

Fig. 5: **The ViibraCane.** In addition to direction guidance by vibration, the cane can be used as an input device to the navigation system.

mode. In navigation mode, the user is always at the center of the (zoomable) map and can therefore gain an immediate impression of the area surrounding him. In virtual mode, the user can zoom and scroll freely and therefore explore other areas that he is planning to visit.

3) Guidance: At the moment, wayfinding is done by a straightforward Dijkstra algorithm that is running on a static and manually built route graph. This is not an ideal solution, as the route graphs have to be constructed in addition to the maps that are being used. However, for the moment this implementation allows us to handle the different kinds of maps we use and to test methods for guiding the user to a desired destination.

The user is guided acoustically by speech output that conveys the direction of the next waypoint in relation to his current position. The output is automatically triggered by every waypoint the user passes and can additionally be invoked at any time during the navigation process.

In addition to the guidance by speech output (or as an alternative to it), we have developed the ViibraCane, an augmented white cane that can guide the user by vibration signals. For this purpose we have replaced the handle of a standard cane with a Nintendo Wii Remote [16]. When the user is walking in the correct direction, no signal is emitted. If the user is veering off the correct direction the handle begins to emit vibration pulses. The length of the pulse allows the user to identify the direction in which he should turn, a long pulse indicating a left turn, a short vibration indicating a right turn. If there is only a small correction needed, the vibration will be lighter, while a larger turn, which often occurs at waypoints, is indicated by a stronger vibration. As the Wii Remote allows only to switch vibration on and off, the lighter vibration is achieved by a constant switching in very short succession. In addition to the guiding with vibrations, the Wii Remote can be used as an input device. All functionality except map access can be triggered by accessing the menu via the buttons of the Remote.

V. Information Sources

Previous versions of the TANIA system used maps locally stored on the system, however static maps are unfit to store additional non-static information about the environment that could help a blind user a great deal. A lot of the required information can be found on the world wide web, such as timetables, information about construction sites, etc. However, this information is distributed on lots of different and often inaccessible websites making it impossible for a blind person to get the required information when it is needed.

By using the Nexus platform as a base for the TANIA system, access to the required information is standardized and from the user's perspective integrated directly into the navigation system. This enables the user to access a wide range of information that is of great profit to his navigational tasks and was previously inacessible to him.

In the following sections we describe different information sources and their integration into our system.

A. Map-Based Information

Maps (or other spatial models) are an integral part of any navigation system. Therefore it is little surprising that maps are needed in order for TANIA to work properly, as it is mainly a navigation system. However, maps can be of varying detail, accuracy, and accessibility. Until now, commercial systems rely on commercial map data, as provided by NavTeq or Tele Atlas, whereas research projects often use maps that are especially suited for the task of blind navigation, but only available for very small areas (normally the test area). Our system is able to use different kinds of maps and can therefore provide the best kind of map available for each area.

1) Native TANIA Maps: Detailed Maps are the indispensable core of our navigation system. The maps we use were developed for the original, stand-alone version of TANIA and were originally stored in GML format. They are built of polygons that are displayed on the tactile-acoustical map and annotated with information (normally the name) that can be presented to the user. If the user taps the tactile-acoustical map, the name of the underlying polygon is announced. If there are several polygons associated with the position, their names will be announced consecutively when tapping the area multiple times, beginning with the smallest polygon. In addition to the objects present in the real world, the maps include purely virtual navigation areas, which are areas connected to certain additional information that might be helpful for a blind user, for example areas denoting a coordinate system in an open space without other navigation cues. The maps are built manually (often based on maps received from institutions, such as our University), converted into an appropriate format and stored in the Nexus platform.

As these maps are the main means of navigation, they are cached locally on the navigation system. This means that a request about all map objects in a certain configurable area around the user (or the area that he is currently inspecting in virtual mode) is sent to the Nexus platform, the response is parsed and all interaction with the map objects occurs locally.

Whenever the user (or the inspected area respectively) gets near the border of the cached area, a new request is started. All parsing is done by a separate background thread and only once a new area is loaded completely it replaces the previously loaded area.

Building floors are realized by a simple string attribute. Consequently, the layering of the floors is not inherent to the attribute and thus unknown to the system. Therefore, so-called "hypergates" have been introduced, which are polylines that have an attribute which references the connected floor and are placed at staircases, ramps, etc. Upon crossing the polyline, the system will automatically switch to the respective floor. As floor-switching can (in contrast to leaving the cached area) occur unpredictably, all floors of an area are cached indiscriminately. Additionally, floors can be automatically switched at RFID tags, which is necessary for situations where Hypergates are not applicable, e. g. at elevators.

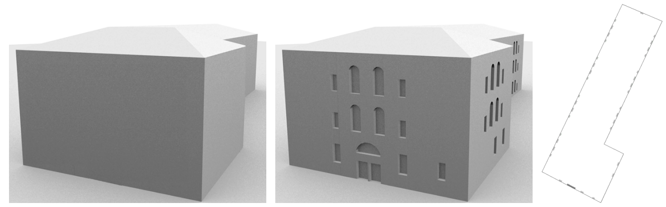
As indicated by the arrow tips in Figure 2, the detailed maps (and the generated façade maps) are used for positioning in addition to user feedback. A collision detection is used to make the positioning more accurate. For this purpose, the map polygons have an additional flag that indicates a possible collision (i. e. a real object like a wall) in contrast to purely virtual polygons.

The drawback of the detailed maps is that they are not available for larger areas. Therefore we try to substitute them with other information as well as possible.

2) Street Maps: Standard Street Maps are commonly used, be it car navigation systems or comercially available GPS navigation systems for blind people. Although they are inferior to our detailed maps, they can still provide valuable information when these are not available. By using the street maps the user is at least able to roughly know his current whereabouts, for example when leaving a bus. Therefore, when there is no detailed map information for the inquired location, we start a simple nearest-neighbour-query to the Nexus platform and give the street's name that is parsed from the response as an output to the user.

3) Generated Façade Maps: Accurate building maps with a high degree of detail as available for some University buildings are usually created manually. Thus, respective maps still only exist for a minority of buildings. However, aiming at the area-wide availability of detailed geometric representations of both the buildings' interior and outer shell, highly automated techniques for building reconstruction are required. A first step in this direction is to automatically generate maps of building envelopes showing façade details such as windows and doors. This section briefly describes an approach for 3D façade reconstruction developed within the Nexus project. The algorithm leads to 3D building models where façade geometries are represented as either indentations in case of windows and doors or protrusions in case of balconies and oriels [17].

Coarse 3D building representations with detailed roof shapes but planar façades — a typical result from airborne reconstruction methods and meanwhile standard for 3D city models — are refined based on additional structural information in façade areas. Façade structures are extracted from 3D point clouds obtained by terrestrial laser scanning. The algorithm involves data driven and knowledge based modeling strategies depending on the quality of the sensor data that the façades are covered with. Façades for which dense and accurate laser data has been observed are modeled using a data driven reconstruction [18]. Thereby, a cell decomposition is generated from laser points which have been measured at the window borders. The resulting 3D cells either represent a homogeneous wall area of the façade or an empty space in case of a window. Hence, they have to be differentiated based on the availability of measured laser points. After this interpretation step, the empty cells are eliminated, while the remaining façade cells are glued together in order to generate the refined 3D building model. These 3D façade structures serve as knowledge base for further processing. Dominant or repetitive features and regularities are detected from the modeled façade elements. At the same time, production rules are automatically inferred. The rules and the 3D façade structures constitute a formal grammar containing all the information which is necessary to generate façades in the style of the respective building. Thus, the grammar can be applied to support the reconstruction of façade regions covered by noisy or incomplete sensor data [19].



(a) (b) (c)

Fig. 6: **Stuttgart's Rektoramt** before (a) and after (b) façade reconstruction and as a generated 2D map (c) with entrance in dark, windows in light gray.

Figure 6 shows the 3D model of our University's Central Administrative Building (Rektoramt) before (a) and after (b) the façade reconstruction. Based on the 3D façade model 2D maps can be derived for each floor where windows and doors are described by annotated polygons(c). Especially the position of the door may be helpful for blind people when searching for the entrance of a building.

In order to further enrich such maps, current research deals with the adaptation of the developed reconstruction strategies to indoor modeling. New challenges arise from the difficult task of indoor localization, poor geometric configurations during data acquisition and unavoidable occlusions caused by a great variety of mobile or static objects. Furthermore, the complex topology of indoor environments, e. g. considering the arrangement of several rooms within a floor, requires the integration of the grammar based concept into a graph structure.

B. Text-Based Location-Dependent Information

There is a wealth of information that an application such as TANIA could benefit from that is usually not available for a context aware system. This might be due to the fact that not all information can automatically be acquired by physical sensors. Another reason is that not all sensors are shared or can be accessed directly. However, some of the missing information is represented in natural language that is in some way connected to a location. Due to this characteristic trait, a navigation system is a very appropriate device to present that information. However, there are fundamental differences between different kinds of text-based location dependent information. These differences cover the format they are stored in, their inherent spatiality, and the way in which they need to be presented to a user.

The inherent spatiality requires some additional explanation. It is not always self-evident, if a piece of information is primarily a textual information or a spatial information. As an example, information about an ordinary street normally consists of its name, location and course. However, the name as such is normally not the information a user is looking for and might even be quite useless if not tied to additional information. On the other hand, a timetable, even though tied to a location, is not mainly a spatial information, the user is interested in the departure times, and the location is a means to ensure that the required timetable is selected.

Normally, the spatiality of an information, its storage format and the way it is presented to a user are directly related, i. e. an information of high spatiality is stored and presented as a map, whereas an information that is highly textual is stored and presented as text (see Figure 7). However, this is not always the case and sometimes, information of high spatiality is stored in text format. Nevertheless, the presentation to the user should reflect the inherent spatiality and not the storage format. As the presentation is usually directly related to the storage format, we chose to change the storage format in order to change the presentation. Therefore we have developed methods to transfer textual content into the format we deem appropriate by analyzing texts. This information is then used to update or augment the world model stored in the Nexus platform.

We invented a framework that we call Text-Sensor that acquires and integrates information from textual sources into our world model [20]. This is done by several steps. First, the relevant information has to be found in the Web. This can be achieved by using Information Retrieval techniques or by defining a specific Web site as textual resource. Next, the textual content has to be analyzed using Natural Language Processing (NLP) methods, since until now all efforts to make the World Wide Web machine readable (e.g. Semantic Web) have not reached the required level of ubiquity. In the final step the acquired data has to be integrated in the World Model. For this purpose we train special matching algorithms which are domain independent. In the following sections we present in more detail three scenarios to augment the World Model by using textual resources.

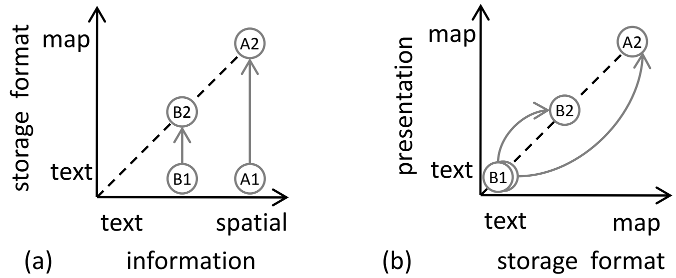


Fig. 7: **Relationship between inherent spatial information and storage format (a), and storage format and presentation (b).** The storage format should be chosen along the dashed lines of (a). Normally, the presentation follows automatically along the dashed line of (b) (a text file cannot be presented as a map). In the case of colloquial area names, the existing information is stored in pure text format, however, the information is highly spatial (A1). By applying the method explained in section V-B1 we transfer the storage format to a polygonal map (A2) thereby allowing a corresponding presentation, as seen in (b). In the cases of Departure Times (section V-B2) and Acquired Live Content (section V-B3), the information is again stored in pure text format. However its inherent spatiality is not as high as that of area names (B1). This corresponds to the fact that the result of our transformation is still textual in nature and just tied to a specific map object, and not polygonal itself (B2).

1) Colloquial Area Names: As our main goal is to assist the blind user in as many situations as possible, we provide region names of different granularities if he wants to know more about his current location or the areas which are crossed when he navigates from one point to another. Conventionally, only regions with geo-political functions (cities, suburbs, states) are modeled in the maps generated by surveyors. Furthermore, people often use other kinds of regions than only geo-political in their daily communication. These can be (i) purpose names for functional regions (e.g. financial districts, business quarters), (ii) vernacular names (e.g. Bohnenviertel) which have a high impact in communication and (iii) spatial names (e.g. Stuttgart-West). We introduced a method to augment the context model whith such regions [21]. The user can get this additional information through the interface described above. This allows him to know if he is inside a shopping zone, on a campus or in an industrial district. As mentioned before, manually creating map resources is very expensive. In order to solve this problem we propose a method to automatically generate such map resources. Our approach uses the World Wide Web as additional knowledge base for this creation process. We begin by collecting names for the above defined regions. These names are then used to build search queries for standard search engines. The resulting pages are downloaded and all textual contents are extracted. Our extractor bases on the context model and uses all street information including their names. This knowledge is necessary to identify all geo-spatial names in the texts. After collecting, all names have to be disambiguated. This is due to the fact that some names are also equal to common nouns and we have to classify the correct reading. In the next step the extracted streets for the requested region are clustered. Finally, the clusters are used to calculate the related areas by using a convex hull algorithm. The resulting region is then inserted into the context model.

2) Departure Times: The source for information on departure times are web pages of Stuttgart's transport association (VVS). The VVS provides — among others — for each public transport stop a page in Wireless Markup Language (WML) containing the departure times of the trains, trams and buses leaving in the near future. These pages are intended for mobile phones with small displays, so they have a rather simple structure and can easily be parsed.

For integrating this information in the Nexus platform, we created an ECS defining a departure table type. Objects of this type have a position and a display attribute, the latter holds the information on departing trains, trams and buses.

The most simple approach to establish a connection between the Nexus platform and the VVS web pages would be to implement a wrapper, which acts like a Context Server to Nexus Nodes and actually reads the data from the web pages. We choose a different approach, which is shown in Figure 3. A standard Context Server hosts the departure table object, whose display attribute is updated once per minute by a small daemon program (EFA DS), which retrieves the corresponding WML page and extracts the information on departures. EFA DS creates a new instance of the display attribute with the appropriate timestamp for each update, so that past states of the departure table are retained.

3) Acquired Live Content: The World Wide Web provides many status messages about the state of things we use in our daily life. Such messages are often not normed, i.e. there is no standard form for these messages. Therefore, there are no comfortable ways, like APIs, to use such information in an application. Futhermore, natural language can not be parsed as simple as a well formatted computer language and more sophisticated approaches are needed. Natural Language Processing (NLP) methods can help to extract relevant information from the Web. For this scenario we are interested in status messages about elevators and escalators to support the optimal navigation for the user. The status messages are posted by the operating company on their web page[1]. The messages have a very rigid format and therefore a rule based system is sufficient to extract the data. We developed a grammar for a finite state transducer to aquire the information. More details about the approach are given in [20], where the domain was slightly different but also comparable to the task of extracting status messages about elevators. One key aspect is to deal with uncertainty and ambigious information. Many spatial objects have similar or equal names. For such cases, the extracting algorithm has to find the best mapping. We use additional information from the textual context, which is also linked with entities in the context model, to obtain the highest probability reading. Nevertheless such a system can never be error-free. It is therefore user dependend how to handle the uncertain extracted information. Some user want to be warned more and others do not want to get more than necessary messages from the system. This is an open issue and has to be considered in the future.

The approach can also be adapted to other domains to augment the context model with other status messages.

[1] http://www.vvs.de/aktuelles/verkehrsmeldungen/aufzuegeundrolltreppen/

VI. A Typical Application Scenario

To demonstrate how the different information sources work together to enable the user in his navigational tasks, we present a typcial scenario where our system can be used. In order to emphasize the general benefit of the system, we chose a scenario not located in the mapped areas of our campus. The scenario is therefore fictious in regard to the mapped locations, however, the technology is working and can be used in the described way.

Suppose that a blind user of our system is in a hotel in a city unfamiliar to him and wants to visit a museum. Knowing that the city has a museum quarter, the user would look for it on the map of the system. Now the museum quarter might not be a part of the provided maps under that inofficial name. However our algorithm has identified the area that is commonly referred to like this and added it to the Nexus platform. Therefore, the user can easily identify it. By exploring the area that is marked as the museum quarter with his fingers, he learns that the area has not been fully mapped yet. So he will have to rely on simple street maps to get from one location to another. He can also notice that most of the museums only have façade outlines, while one has a completely mapped interior. Let us assume that the user decides to visit one museum that is of particular interest to him and the fully mapped one, because of the convenience.

As the museum quarter is too far away from the hotel he has to use the commuter train to get there. The system allows to search for the nearest commuter train station and have a look at the departure times. If an adequate service is provided by the commuter train operator, this information is not just based on timetables but actual approximated departure times depending on the current position of the train in the network. Based on that information, the user can for example decide to have another coffee in the hotel lobby, instead of having to wait at the station. In order to find the way to the station, the user has to rely on standard street maps, as there is no special mapping for this area. This certainly is something for the more adventurous of users and similar to the use of a current commercial GPS navigation system for blind people. Arriving at the station, the user is informed that the elevator that leads to the platform is out of order. This piece of information was present in textual form on the website of the commuter train operator and automatically integrated into the Nexus platform by our algorithm. On the platform the user can again rely on the departure times in order to catch the correct train.

Once arriving at the museum quarter the user can find the way to the entrance of the façade-mapped museum. At the museum that is completely mapped, he can also use the system inside. Here the system is not only used for navigation but also to convey information about the items on display. The user can listen to additional information about the items on display at any location that has been enriched with metadata by the museum.

VII. Conclusions

We presented the architecture and implementation of our navigation system for blind people based on a general support platform for location-based applications, which allows for the first time to integrate information from many varying sources and display that information on our tactil-acoustical map. The tactile-acoustical map has been developed earlier and blind users have attested that it is an effective way of relying spatial information. Several algorithms that make information available from both real-world-sources and the web have been devised and implemented. It is not yet possible for users of the system to share relevant spatial information with other users, however, the integration of the Nexus platform is a first important step in that direction.

VIII. Acknowledgments

This project is funded by the Deutsche Forschungsgemeinschaft within the Collaborative Research Center 627 "Spatial Models for Context-Aware Systems". We would like to thank Lorenz Kley and Klaus Bosse for their invaluable coding and mapping work.

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