Landmark-based Navigation in Complex Buildings

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***Abstract*—Growing numbers of mobile devices in our daily life and their capability to fulfill challenging computational tasks raise the question about new application fields beyond well-established tasks. While outdoor navigation became a standard task for many mobile devices, indoor positioning and navigation is still in the research and development stage. Even though complex buildings require aided guidance for visitors, today's mobile hardware is not able to deliver a reliable indoor navigation system.**

In this paper we describe a novel information system for indoor navigation in complex buildings. Users are guided through the building by using images of the surroundings and textual instructions. We avoid hardware-based user positioning due to its known drawbacks. Instead, users are involved into the navigation process and complete missing information through recognized context and logical constrains of their surroundings. The human navigation process based on recognition of certain unique locations and visual clues is the foundation of this work. The proposed system is universally applicable without restrictions on navigation devices or existing hardware in the building.

I. Introduction

Mobile devices of all kinds penetrate our daily life and change it significantly. The build-in hardware becomes more complex and consequently, the range of application steadily grows.

Navigation is one of the many tasks that nowadays devices master. The satellite-based Global Positioning System (GPS) became the standard for outdoor positioning in recent time. There exist not only stand-alone navigation solutions but many of today's sold mobile phones include the required soft- and hardware for outdoor navigation. However, there are limitations in the field of application for such devices. Even though navigation tasks on street level are very precise, the GPS approach reaches its limit at the entrance of a building. Since nowadays architectonic styles are changing to more individual and often more complex structures, it is indisputably important to support visitors in such complex buildings as airports, railway stations, hospitals, and museums. Completely new navigation routines are often required to navigate a person inside unfamiliar buildings. For this task exist several hardware-based solutions as well as approaches working solely with logical constraints of the building and human perception. This paper describes a new approach for indoor navigation in complex buildings. We especially aim for a generally applicable solution, i.e., the resulting system should work in any building independent from any compulsory hardware infrastructure or other mandatory requirements. Avoiding strict requirements for technical infrastructure in the building as well as hardware constrains in the navigation device requires a new navigation concept. Our navigation system does not depend on a precise geographical positioning of the user in the building. We include the user into the navigation task by letting her subconsciously collect visual impressions about her surroundings. She then actively informs the system about her position in the building by selecting certain areas from a list of preselected positions. A special data structure called building-graph represents the complex building and all possible connections between the areas. Using the physical constrains of the building and the human power of observation, we are able to design a generally applicable navigation system. However, even though this system does not require hardware positioning, we will use existing infrastructures in buildings for user support. They will be included as a best-effort approach to estimate user's position in the building-graph within a certain deviation area. This approach reduces the amount of choices users have to consider.

Usability and precise instructions are further goals of our system. The navigation steps need to be self-explanatory and the presented information has to be reduced to the required minimum. This way user's cognitive load can be significantly reduced and a more natural navigation experience is made possible. Additionally, by optimizing presented information, we provide a more suitable visualization for the small displays of smartphones.

This paper is structured as follows: Section 2 introduces several navigation models and presents techniques for indoor positioning and navigation. In Section 3, we describe the idea behind our navigation approach. Additionally, this section covers the data structure which is the foundation of this navigation approach and depicts the implementation and architecture of our system in more detail. In Section 4, we present the evaluation of our system. Finally, in Section 5, we summarize this paper and future steps in the system development are revealed.

II. Related work

In this chapter we want to highlight relevant concepts and research work in the area of indoor navigation. Several space models as well as different positioning techniques and navigation approaches are described and discussed.

A. Navigation models

Navigation models describe different ways to represent an environment in a navigation system. Leonhard [17] differs between three navigation models. Geometric space models

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base on precise positioning of the user in geographic coordinates. These are either relative to a pre-defined point in the building or to earth's global coordinate system. Thus, a precise localization of the user is mandatory. Today's navigation devices work by using this space model.

Symbolic space models divide the surroundings into logically closed areas. These areas differ either in their visual characteristics or in spatial separation. Single areas are logically combined to a single grid structure. Thus, users are led through the building either by their geographic coordinates or by their logical position in the grid.

Finally, hybrid space models form a combination of the first two space models. Users navigate through a graph-based structure but are allowed to switch into a more detailed representation of the building that is based on their geographic position.

One further approach for environment representation are semantic space models [3], [5]. These models identify user's position based on her actual context. Such context may be: user needs to keep an appointment at a certain time, she logs into a computer which location is known to the system or she has daily repeating tasks. Positions withdrawn from this information can then be used for localization purposes.

B. Positioning techniques

Nowadays, several techniques for indoor positioning systems are subject to research. Most of them differ in accuracy, signal coverage, installation and maintenance costs, and hardware dependency. In this section we describe the most common research projects and address their strengths and weaknesses.

Satellite-based Positioning System (GPS) is built into many mobile devices nowadays and forms the most widely used outdoor localization system [9]. Even though GPS signals are blocked by walls and thus GPS is not applicable on indoor localization in the standard setup, repeater systems like **Pseudolites** [16] are able to carry those signals into indoor environments. This allows users to use common mobile devices without further hardware changes for navigation purposes.

Tracking **Wi-Fi** signals is another approach that avoids additional hardware and thus is universally applicable to many buildings. This technique, known as Wi-Fi fingerprinting [4], [15], is the main focus of today's positioning research due to its accuracy, low installation costs, and usage of existing infrastructure.

Additionally, further techniques based on light, sound, and radio signals complete this group. Approaches based on **infrared, ultrasound, ultra-wideband, Bluetooth, RFID,** and **NFC** allow a very precise positioning of the user [9]. However, all of those approaches require additional sender or receiver nodes in the building as well as special navigation devices.

Another approach that works with existing sensors in mobile devices is the **Inertial Navigation System (INS)**. This system uses the build-in compass and accelerometer in mobile phones to calculate the walked route [18]. Even though this system is independent from additional hardware, it is highly error-prone and rarely flawlessly usable outside of laboratory conditions.

Build-in cameras in mobile devices can be used for **computer vision** to provide an alternative way of environment recognition [10]. However, image recognition has a complex setup and therefore does not suit a general applicability which is aimed in our application. Another way of positioning is done via 2D-Codes [13], [11]. Such codes may include the coordinates of the location and after scanning one label the system consequently discovers user's position. Camera data can also be used for augmented reality [11]. Here, users observe their surroundings through the device's video stream which is enhanced with additional data, e.g., POIs, directions, routes. However, this representation approach relies on very precise positioning of the user and is often not applicable to indoor environments.

In retrospective, all those mentioned localization techniques have the same short-comings in common. Most approaches require an additional hardware setup in the building or navigation device or are known to be error-prone. Thus, these techniques are only reliable to a certain degree. There exists a second group of approaches based on symbolic space models which works with areas in buildings and thus does not rely on precise positioning.

The following approaches base on the idea of supporting positioning through the data structure. Thus, the system is more independent from the existing technical infrastructure in the building.

The navigation approach presented by Chowaw-Liebman et al. [4] provides an advanced data model for buildings. Users follow generated textual instructions and thus is guided through the graph structure of the data model. The position of the user is monitored via the device whispering approach [15] during the navigation.

Baras et al. [1] presented an approach that leads users through a building without any hardware-based positioning. Here, a model of the target building provides the route based on area identifiers such as room names or special locations. Objects which base on these identifiers are logically connected. Users are following the sequence of locations and reach their destination. However, the presented system provides very sparse information which lacks details. Furthermore, all information is presented as text, therefore, users need to be familiar with the building to follow the route.

Another approach working with the symbolic space model was introduced by Jensen et al. [12]. The presented system encloses areas to logical objects which are connected in a building graph. Human movement is tracked by a technique based on RFID signal recognition. Even though this positioning approach shares the drawbacks of all hardware-based positioning solutions, the graph on its own provides strong constrains for possible actions within the building and thus the introduced navigation approach is still reliable. A proper building structure enables flawless navigation for this approach.

Landmark-based navigation for outdoor scenarios was examined by Beeharee et al. [2] as well as by Christian Kray [14].

Both approaches used depictions of areas as well as textual descriptions to guide a user to her destination. These solutions were merely dependent on precise positioning. The overall results were promising but they cannot be simply transferred on indoor environments. Amongst others, special cases like missing technical support for user positioning, multiple floors, identically looking locations, and the closeness of the environment need to be considered and require an extension of these approaches.

Apparently, it is possible to navigate a person through a building without precise hardware-based positioning. To develop a universally applicable, cost-effective, and reliable indoor navigation system, we will focus on the presented findings and combine the techniques for improved results.

III. Landmark-based indoor navigation

This chapter describes the approach for our navigation system in detail. First, we explain the idea behind the navigation approach, followed by the navigation data model of our system and the user interaction model.

A. Navigation approach

The concept of the developed navigation system follows the human cognitive navigation process. Subconsciously, the human brain constructs a unique cognitive map from the starting point to the endpoint of the route which is divided into single route sections of manageable sizes characterized by waypoints and landmarks known or communicated to the user [8]. A landmark is a unique recognizable reference point in a section used for orientation and positioning of the user, whereas a waypoint is a special kind of a landmark, namely the starting or endpoint of a route section. Hence, the route consists of a sequence of waypoints which the user needs to pass in a predefined order. Each of these waypoints is connected to one or several landmarks which make this exact position visually unique in the context of the routing. During the human navigation process, a mental depiction of the route, the cognitive map, is continuously compared to the surroundings.

This subconscious procedure is modeled in our navigation system. However, this approach does not only model the human navigation process but also human instructions in case of asking other people for the direction to a destination point. People tend to describe the route by providing two to three landmarks which are located on the way and build the directions using these unique areas. Our navigation system is based on the same principle. A route along waypoints is computed after defining starting and endpoint. The navigation system displays successively the next waypoint the user has to pass until she reaches the endpoint. To facilitate the navigation for each waypoint, textual instructions are attached which describe how to reach the waypoint from the current position. Additionally displayed landmarks allow a continuous verification of the current position along the route.

The user is actively integrated into the navigation process by confirming her arrival at the target waypoint to be navigated to a successor located on the route.

B. Navigation model

In this section, we will focus on a data model called building-graph. In our system, on the one hand the building-graph is used as a structure the navigation relies on. On the other hand the system provides a module to construct such a structure for an arbitrary building.

The graph consists of nodes and directed edges. The nodes represent a specific logical area in a building which comprises unique attributes, e.g., the entrance hall. They are used as navigation points and can obviously be applied as starting points or endpoints. We distinguish between waypoints which depict landmarks lying on the route and points of interest which are relevant navigation endpoints and a subset of waypoints. Both are discussed below.

The edges represent all possible routes between the nodes in the specific building. They have to be directed edges because some routes can be restricted with respect to their direction of movement, e.g., an escalator. Every edge contains a rough distance value between the connected nodes such that the user can estimate how long she has to walk to reach the next waypoint and can easily compare sections. An estimation of the distance is sufficient since a person can hardly estimate accurate distances in buildings [6]. During the construction of a building-graph, we assign a geographic direction to each edge to compute the angle between two consecutive sections. In dependency on the angular degree, the user can be precisely navigated by adapting the textual instructions according to the computed value, e.g., turn left, turn right, turn around, follow the route. The direction patterns base on work by Chowaw-Liebman et al. [4].

C. User interaction

Users interact with our navigation system in three different ways. In the first step, immediately after the system start, the user selects her starting point either from a automatically suggested set of nearby locations or through manual selection from the set of all existing position. In the next step, she assigns her destination point from a predefined set. Based on this data, the system leads her through the building. It proposes one direction and one landmark at a time and the user confirms her arrival at the landmark in each single step. Additionally, she is able to check the right way by comparing passed landmarks to proposed ones. User interaction is depicted in the sequence diagram (see Figure 1).

IV. Implementation

This chapter covers the implementation of our navigation system. We introduce the architecture of the system and describe the building graph and the user interface in detail.

A. System architecture

The main focus for the architecture of our navigation system lies on expandability and modularity. New modules should

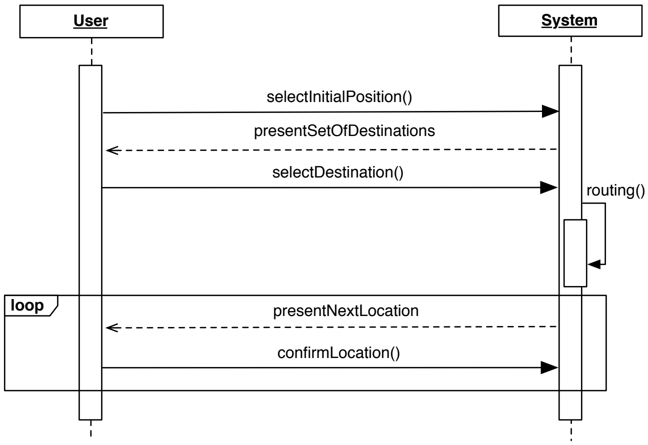


Fig. 1: User interaction

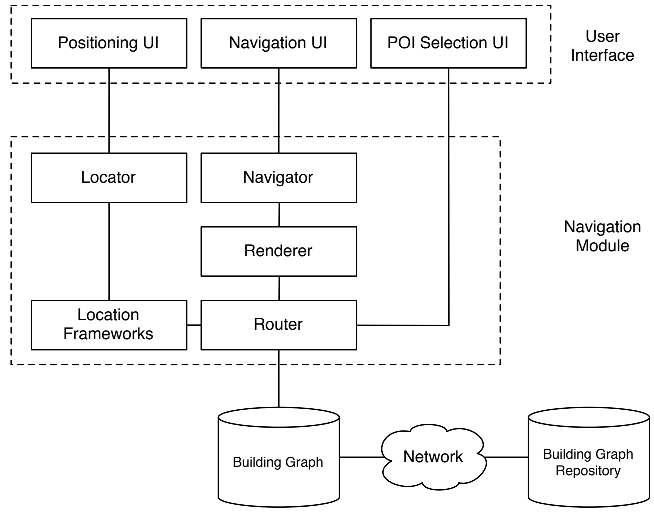


Fig. 2: System architecture

be easily included into the system. The proposed navigation system does not rely on hardware-based positioning. However, existing infrastructure in buildings is used for position estimation through so-called location frameworks. In the first implementation GPS and Wi-Fi were used for this purpose. It is easily possible to include new frameworks such as NFC or Bluetooth for advanced positioning of the user.

Furthermore, this system will distribute data dynamically to users. The required building graph is identified by the address object. After selecting a start- and an endpoint, we are able to calculate the route through the graph and thus only download detailed information from the server for waypoints which are part of the route. This way we guarantee a reduced memory footprint which is beneficial for efficient mobile communication.

The following Figure 2 depicts the architecture of our navigation system. In the first step our system requests building data for a specified area from a central server. Based on this data, a routing module calculates the path from user's position to her chosen destination point. Existing location frameworks ease the selection of this route by approximating the position of the device. A rendering unit converts the calculated path into textual directions, extracts all required images for landmarks, and finally builds up the navigation module.

B. Building Graph

A building graph is identified by the address of the respective building. This way, we are able to precisely download only required data chunks and thus lower our memory footstep.

A building is subdivided in different areas, e.g., different floors, departments which distinguish in a logical matter. An area can be a subarea of another one, e.g., there can be several departments on the same floor of a building. Partially intersecting areas are not considered in our implementation.

Another important entity is a landmark. A landmark is a unique recognizable reference point used for orientation and positioning. It contains pictures of the reference point from the user's point of view, an identifying name, GPS-coordinates, and Wi-Fi fingerprints. The two latter attributes are necessary because a landmark just as a waypoint can be suggested to identify the starting point in the navigation process.

A waypoint is similar to a landmark and is described by the same attributes. The difference is that a waypoint contains a set of landmarks which are visible from this point and is not necessarily a discrete object. In fact, waypoints represent the nodes of the building-graph, i.e., the starting points and endpoints of every section of a route which have to be reached to continue with the next section, e.g., branches or stairs to the next floor. A point of interest (POI) is a special waypoint which can be the target of an entire route. They additionally contain a textual description of the target. A waypoint is associated to the area it is located in and to other adjacent waypoints by segment objects. Segments correspond to the edges of the building-graph and have to fulfill the attributes discussed above. Especially, all landmarks positioned on a section are included into such a segment.

Landmarks and POIs are collected in logical categories: LandmarkCategory, POICategory, and POISubcategory. Landmarks are categorized by included attributes, e.g., stairs, corridors, pillars, lifts.

POICategory and POISubcategory are used to facilitate the manual choices of the endpoint.

To support the user by determining her starting point, GPS-coordinates and Wi-Fi fingerprints are assigned to landmarks and waypoints. With the appropriate infrastructure, the navigation system can suggest possible starting points based on hardware positioning. A GPS object contains a latitude, a longitude, and an accuracy value and refers to every landmark and waypoint with the same coordinates. The accuracy value specifies the accuracy during the measurement to determine the coordinates of a point in a building conditioned by shielding. The system suggests only estimated points whose coordinates stay within this value.

Wi-Fi fingerprinting uses the signals of Wi-Fi access points for positioning. To determine the user position, the measured fingerprint of the navigation system is compared to the fingerprint objects in the database. Hence, every Wi-Fi fingerprint object requires the creation date, the access point identifier (SSID), the signal strength, and the references to the considered landmarks and waypoints.

C. Navigation module

The navigation module transforms the route description from the building graph into an appropriate visual representation with respect to the defined user interaction protocols. It is crucial to provide a self-explanatory, intuitive interface that supports users through the task of navigation. Furthermore, this component is responsible for locating user's initial position in the building graph, calculating the best path through the building and rendering textual instructions according to the steps on the route. Following sections will depict these tasks in more details.

1) Initial user positioning: For a proper navigation it is crucial to identify user's initial position accurately. Even though several technical solutions were presented in Chapter II, it was shown that none of those approaches suit our solution well enough. Existing drawbacks, e.g., dependency on additional hardware or error-proneness, hinder a reliable user positioning based solely on one single solution. Thus, hardware-based approaches will only be used to support our main positioning technique: observations made by the user. The proposed approach relies on visual perception of unique features in the surrounding area and a robust mapping of those spots on the building graph.

We implemented two ways of informing the system about the position of the user. The first method to identify user's location requires hardware-based positioning. The first implemented software version tracks Wi-Fi signals to build up a rough estimation of user's position. We assume that Wi-Fi tracking delivers an approximate position within a predefined deviation area. This deviation area depends hardly on the environment, i.e., number of Wi-Fi access points, architecture of the building, quality of navigation device. In our test environment, a considered deviation of 15 meters proved to be a convenient value. Our algorithm selects all landmarks within the deviation area and presents images of the selected areas to the user (see Figure 3(a)). Then she compares shown images to her present observations and selects her current scene. The selected landmark is then tracked back over the associated segment element to the linked waypoint which marks the initial node in the navigation route.

In case of malfunctioning or non-existing hardware-based positioning, users may switch to the manual selection from a set of all landmarks. We implemented a filtering option based on landmark categories to ease the selection of the initial area. Such categories are stairs, shops, entry points, entrances, corridors, and other unique features. Users choose environment characteristics from a set of categories and consequently filter the set of displayed landmarks. Therefore, selection of two to three categories reduces the displayed landmarks significantly and allows much faster positioning. Calculation of the initial node is done analog to the automatic suggestions component.

2) Destination selection: Additionally to a reliable initial positioning it is important to clearly select a waypoint in the building graph as a destination point. This happens analog to the approach described in the previous section. First, the user selects one matching POI-Category from the list, e.g., rooms, restaurants, shops. A second list is displayed containing all POI-Subcategories which were included into this category. The selected POI-Subcategory is either connected to a single, well-defined POI in the graph or to a general term, e.g., restroom, ATM, phone booth. The user is then led to the nearest POI which corresponds to that subcategory.

3) User navigation: After a proper selection of a starting point and an endpoint, our system calculates a route through the building using Dijkstra's shortest path algorithm [7]. In our working environment with several hundred navigation points in the building graph, this algorithm is able to calculate any route within a reasonable time of few hundreds of milliseconds.

Based on this routing, we render all relevant information for navigation. The navigation view contains two important elements: textual instructions which are built after calculating all route segments and graphical representations of relevant landmarks on the way to the endpoint.

Textual instructions are important to guide users from one navigation point to the following. Such instructions include the approximate length of current route segment, walking directions, and the name of the endpoint. Walking directions are derived from angles between prior and current segments of the route. These values are converted into human readable instructions, such as "Turn slightly left and follow the route for 20 meters". Waypoints on different floors are displayed accordingly, e.g., "Go one story up to the 1st floor".

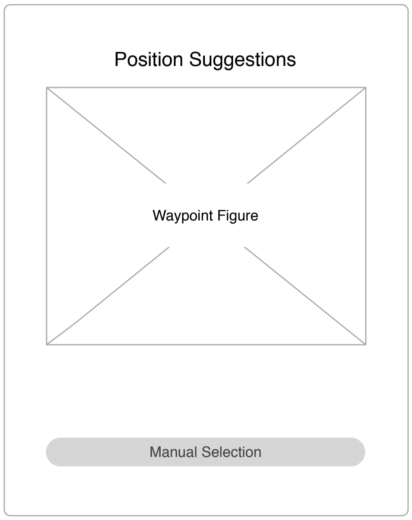
Additionally to the values for direction and route length, landmarks which can be perceived on the route and the waypoints from the beginning and the end of the route are fetched from the database. These objects provide visual clues for the user. She is then able to adjust her position to her cognitive map of the building and make sure that she follows the correct route.

D. User interface

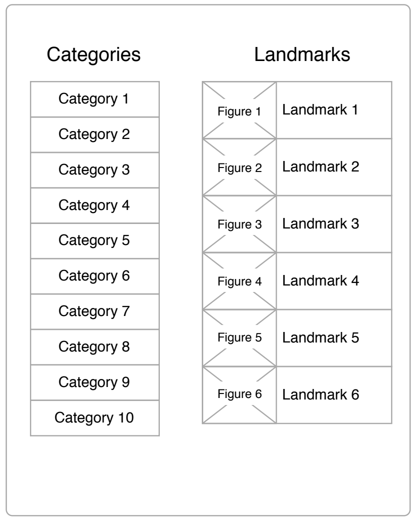
Three different views build up the main user interaction stack for our navigation system. The first view (see Figure 3(a)) depicts landmarks in the surroundings which are automatically selected by the system as possible user positions. In case of missing sensor-based positioning infrastructure in the building, the user is able to select landmark characteristics and her position from a list (see Figure 3(b)).

The following destination selection view displays the POI-Categories and POI-Subcategories in two text tables. The POI-Subcategory table contains entries based on the previously selected POI-Category. Thus, the presented choices are displayed in an easily understandable manner.

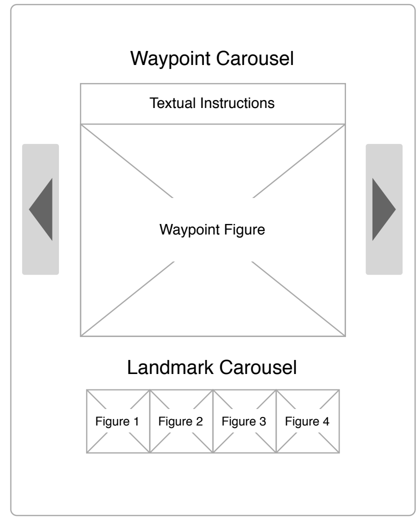
In the final view, all necessary components for navigation are



(a) Automatic position suggestions



(b) Manual position selection



(c) User navigation

Fig. 3: Sketches for user interfaces

combined and form the user navigation view (see Figure 3(c)). This main element on the screen is the waypoint-carousel. It includes the generated textual instructions as well as additional descriptions of the surroundings and the picture of the final waypoint for the active route segment. This module always depicts one single segment of the route. Once user's view matches the depicted landmark, she may go on to the next segment by pressing a button.

Underneath the waypoint-carousel follows the landmark-carousel. It contains all landmarks which lie on the segment. Their purpose is to provide users with additional information about the route. Whenever she observes one of the landmarks, she can be certain to follow the right path. The final realization of the user interfaces is illustrated in Figure 4(b) and 4(a).

V. Evaluation

In this section we discuss the evaluation of the implemented navigation system. Every participant has to pass two test routes within a building. On one test route she uses the implemented software, on the other one she searches her endpoint with one of the two alternative navigation methods: verbal assignments by the receptionist or the floor plan of the building. Afterwards, the different approaches are compared based on time measurements and user feedback.

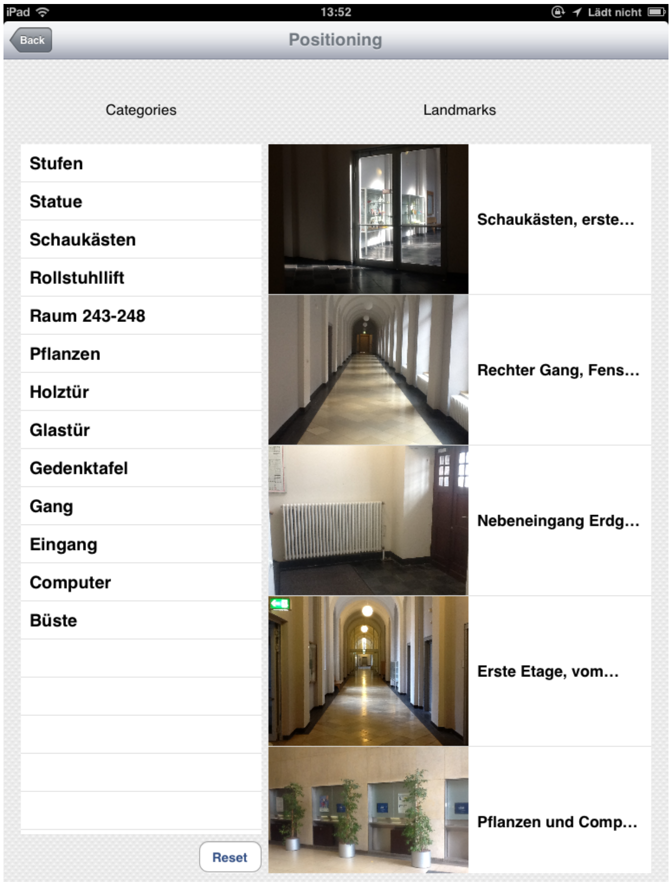
A. Test procedure and setup description

The depicted navigation system was implemented in Objective-C on the Cocoa-Framework. During the test procedure the software ran on an Apple iPad 2 Wi-Fi with iOS 5.0.1.

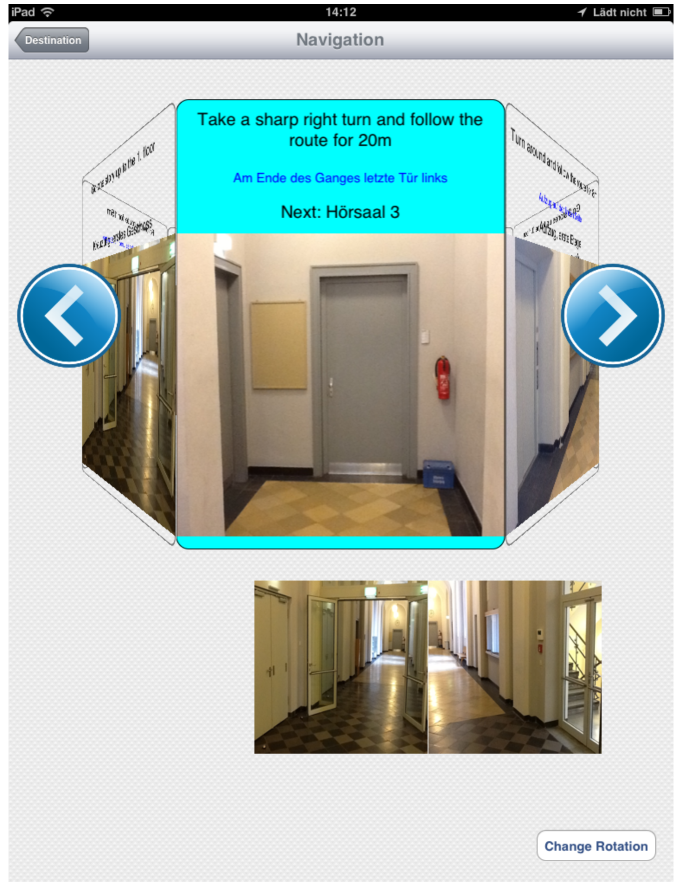
The main building of RWTH Aachen was chosen to conduct the user tests. This building has a complex architecture. It is rambling and consists of three upper floors, two basement floors, different kinds of stairways, and elevators. Although many university departments are located in the main building, most students are not acquainted with this building, thus, it can be assumed that the test results are not distorted.

Two test routes of the same length and complexity were selected for the test. Each of both routes lead from the front entrance to two target rooms and back again. The first route leads the participant from the main entrance to a lecture hall on the first floor in the left wing of the building. This room is not signposted and the entrance is hidden behind a pillar. Afterwards, she has to attain a room on the sparsely frequented third floor and return to the starting point. The second route leads the testee to the right wing of the building. On her way, she has to find a room on an intermediate story between the first and the second floor. By using the implemented standard version of the navigation software, it is yet not possible to locate a point on an intermediate story. Therefore, additional textual descriptions are added to such POIs. Next, the participant is instructed to visit the university's post office located in the basement of the building. Finally, she returns to the main entrance.

The test group consisted of 3 female and 11 male students aged between 19 and 30. They had to pass one route with the navigation system and the other with one of two alternatives. Six of them used the oral instructions from the receptionist, the other eight participants used a very detailed building map. Required time, chosen routes, deviations in usability of the navigation system, and comments of the participants were written down during the study. The main part of the evaluation bases on an online questionnaire. Users could evaluate the application and the alternatives, write comments, and rate the usability of the system.



(a) Manual position selection



(b) User navigation view

Fig. 4: Application components

B. Outcomes

The first part of the evaluation comprises the time comparison between the navigation approaches. It was considered to use routes of the same length and difficulty in regards to indoor navigation. Differences between the navigation approaches could be determined by comparing single sections of both routes. The essential differences could be highlighted by comparing the two routes using the mentioned navigation methods. Overall, the navigation system performed equally well or better than the two alternatives (see Figure 5). The two alternatives to our system revealed clear short-coming during the navigation process. The use of maps revealed weaknesses in complex parts of the building, e.g., finding the room on the intermediate story. This implies that users can hardly comprehend challenging parts of a building by using a common floor plan. Increased complexity of the route consequently increased the time for the guidance by the map. The verbal explanation has been partially fragmented which led to longer navigation. Participants had often to increase their searching space and thus only found the POI by a coincidence. Even though the receptionists were trained for advising visitors in the building, their instructions were often not well-understood by the users. Presumably, directions by random passengers would be more questionable and vague.
Our indoor navigation system performed better in case of the route becoming complex. In this situation, the environment often did not match the cognitive map of the user and consequently confused her. Otherwise, if the navigation route is well-structured and can be easily visualized in a cognitive map, analog alternatives allow the user to reach her destination more quickly since most of the navigation tasks are completed on the fly in the human mind.
In the following, we describe the evaluation results of the implemented navigation system. The participants interacted with the system as expected and successfully recognized the starting point, endpoint, and the landmarks. Important findings were made during the user study. Stopping in the middle of a corridor only by using landmarks did not work for the most participants. Since we are working with approximated, imprecise locations, additional textual instructions are absolutely necessary to deal with that problem. Furthermore, we found out that glass doors require to have a separate landmark. All users expected a new instruction when they arrived at such glass doors and were confused not finding the picture of the displayed landmark on their iPad, even if it was clearly

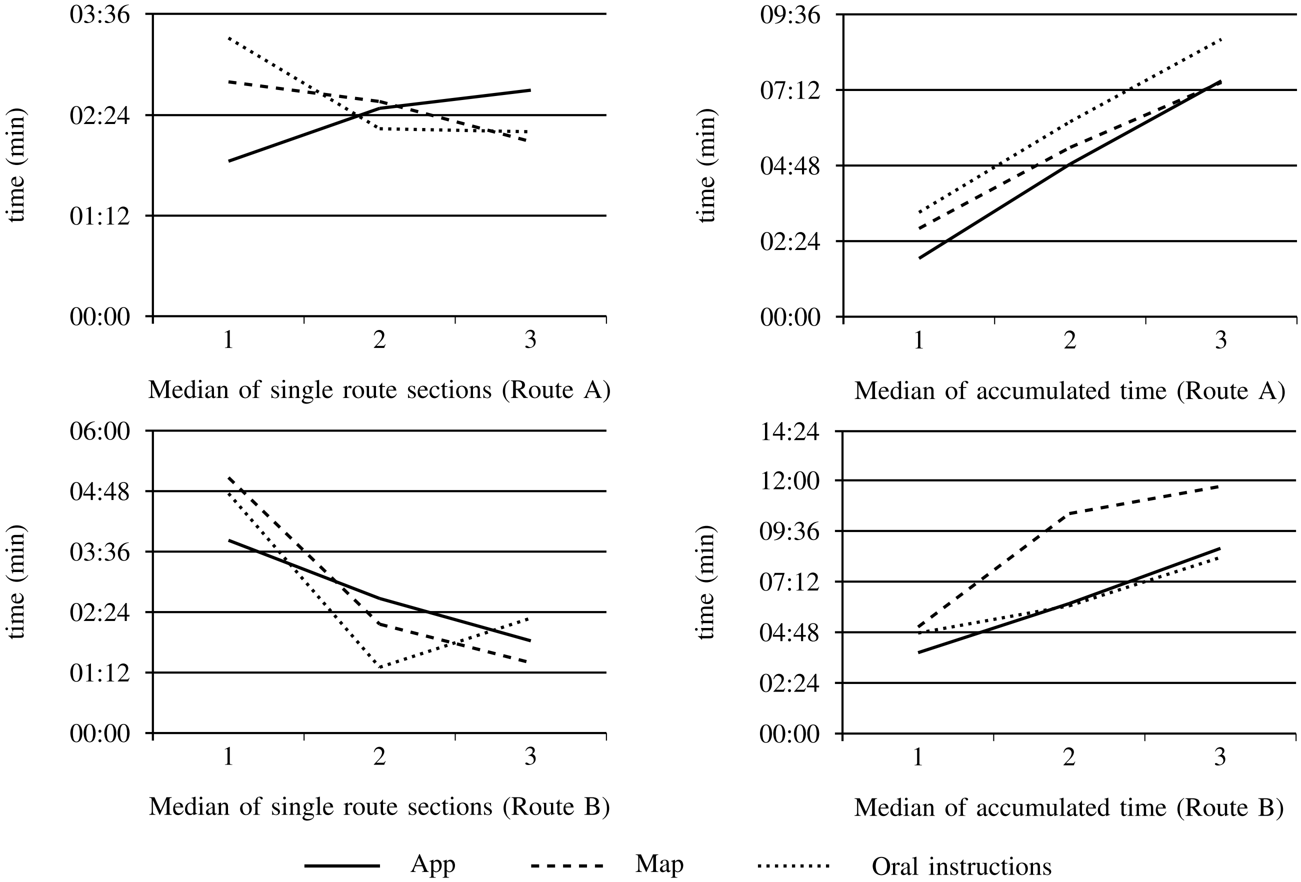


Fig. 5: Time measurements for two routes with three segments

visible behind the door. As mentioned before, it is crucial that landmarks are depicted from the user's point of view. Slight shifted vision angle of the depicted view confuses most participants and the user tends to turn in the same direction. Consequently, textual instructions do not work in this case.

A crucial problem occurred when parts of the building look identically. For participants, it was not possible to distinguish similar waypoints and landmarks. By consulting the textual instructions they tried to deduce the right floor. In such cases, the textual instructions absolutely conduct the navigation. It is then very important to provide unique cues for the context of the user.

The usage of the additional landmarks which lie between to waypoints appeared as redundant. Almost nobody considered this additional information, even in situations when such clues were helpful and the participants were confused and disoriented. In further implementations the additional landmarks should be omitted or partially integrated into the waypoint-carousel.

Altogether, the navigation system performed very well. The software proved to be user-friendly and most participants could imagine to apply it in their daily life. Furthermore, the navigation software was classified as the most reliable considered method because people were able to validate their movement during the navigation process.

Finally, 57% of the testees would prefer navigation with the applied software over the compared alternatives. Participants named uncertainty in dealing with the software for being the main reason to prefer analog navigation approaches. On that point, it should be considered that the software is in an experimental stage and many extensions are in progress. We assume that later iteration stages of the implementation and familiarization with the software would increase the acceptance rate.

VI. Conclusion & Future work

Buildings represent an insuperable barrier for existing navigation systems. Although there exist approaches for indoor navigation, they suffer from various disadvantages. A new approach for navigation in complex buildings was examined in this work. It focused on an universally applicable concept in combination with an intuitive and user-friendly handling.

The evaluation revealed that reliable indoor navigation can be accomplished by the provided implementation. The proposed solution improves indoor navigation under certain circumstances compared to classic solutions of way finding, such as a building map and oral instructions. This system can even be further improved with the knowledge gained during the development and evaluation. Some of the possible improvement steps could be extracted from this work.

The implemented navigation system should open up the area of mobile phones equipped with smaller displays. The user interface has to be revised, i.e., a compromise between the size of a waypoint illustration and the amount of depicted information needs to be found. Additionally, the landmark carousel has to be integrated into the waypoint carousel.

Furthermore, the building-graph has to be extended. It should be possible to map intermediate floors and areas with many branches. Another aim is to automatically reduce the sections of a route and the textual instructions without complicating the navigation. It was proven that an increased number of segments in a route leads to a distorted perception of this route's length [19]. The route tends to appear longer than it really is.

Furthermore, in our next steps, we want to analyze the usage of pictographic illustrations instead of textual navigation instructions, e.g., arrows will be compared to textual instructions. Pictures are perceived faster than textual instructions but usually contain less information than their written counterparts. It has to be examined whether the pictographic instructions can completely replace the textual instructions or just expand the information.

Finally, we plan a user study in the Cologne-Bonn airport to evaluate our navigation system in a real-world environment. This building complex allows us an evaluation of a large areal with a highly frequented pedestrian traffic.

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