Developing Landmark-Based Pedestrian-Navigation Systems

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***Abstract*—Pedestrian-navigation services enable people to retrieve precise instructions to reach a specific location. However, the development of mobile spatial-information technologies for pedestrians is still at the beginning and faces several difficulties. As the spatial behavior of people on foot differs in many ways from the driver's performance, common concepts for car-navigation services are not suitable for pedestrian navigation. Particularly, the usage of landmarks is vitally important in human navigation. This contribution points out the main requirements for pedestrian-navigation technologies and presents an approach to identify pedestrian flows and to imply landmark information into navigation services for pedestrians.**

***Index Terms*—Landmark orientation, navigation, pedestrian telematics.**

I. Introduction

DUE to an expanding volume of traffic, of traffic congestion, and an increasing number of accidents, the development of traffic-telematic services has been initiated in order to improve transport safety and to avoid capacity overloads. Transport-information services provide positioning systems, safety relevant applications, and infrastructure-based traffic-management services. Onboard-navigation services are seen as key technology for transport-telematic services, enabling drivers to locate their actual position, to define an optimal route leading to a desired destination, and to react on actual information about traffic jams, road construction, parking availability, etc. In the late 1980s, the PROMETHEUS project was initiated in Europe, where the formal basis for current in-car navigation services was laid down [1].

The global positioning system (GPS) is used to plot the location of a car and to assign its position to road-related datasets. The geographic data files (GDF)—a European standard that is used to describe and transfer road networks and road-related data—serves as basic dataset for car-navigation technologies. It provides information about distances, directions, street names, and specific "points of interest" (POI).

Although navigation systems have primarily been developed for vehicles, technological progress has led to the construction of small and cheap components, allowing the design of mobile devices for pedestrian-navigation services. This enables the provision of navigational aid to people at any unfamiliar place. Especially in surroundings like public buildings such as airports or train stations, navigating individuals often fail to find their way immediately under time pressure and would, therefore, benefit from a system offering navigational information via mobile devices. An overview on existing pedestrian-navigation systems and some of their advantages and disadvantages can be found in [2] and [3].

The development of pedestrian-navigation services calls for further research to obtain an improved understanding of pedestrian spatio-temporal behavior. The main goals in the design of navigational tools are to ensure the efficiency of infrastructure and the individual comfort and safety. This includes both individual benefits (such as walking efficiency, safety, and time-reduction) and the opportunity to control pedestrian movement and flow within an infrastructure or a local neighborhood to avoid obstructions and accident hazards.

The application areas of pedestrian-navigation and information systems cover many different ranges.

- *Tourism*: Navigation systems can support the traveler's orientation in unfamiliar environments and offer the provision of routes leading to different attractions, supplying additional information about them.
- *Business trips*: Navigation systems offer navigational aid to lead the user rapidly and comfortably to the desired goal.
- *Recreational trips*: Navigation systems provide spatial information for climbing, wandering, or tramping users, including the important aspect of additional aid in case of emergency.
- *Rescue services*: Navigation systems are already used for location of casualties, as well as for self-orientation of rescue teams in areas with low visibility, e.g., smoke-filled buildings.
- *Individual navigational aid*: Users with specific demands like handicapped or elderly people are able to receive customized service and information packages.
- *Military and security operations*: Localization and information technologies are used by soldiers to self-locate, collect, collate, and convey information.

For pedestrian-navigation systems, GPS and GDF turn out not to be sufficient as the data basis. The localization accuracy of satellite-positioning systems is satisfactory for car navigation but insufficient for pedestrians. Routing instructions based on the data and concepts of current car-navigation systems offer mainly turning instructions and metric-distance measures; additionally, certain POIs are provided, although the selection of

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these points seems to be more or less arbitrary and does not consider their quality as navigational aids. Nevertheless, findings in spatial-cognition research reveal that humans need salient objects for orientation and navigation and that navigational instructions given in pedestrian-navigation systems improve when referring to these objects [4]. These objects, so-called landmarks, serve as reference points in the environment, which help to structure space and support navigation by identifying choice points, where navigational decisions have to be made.

Based on several findings in human-navigational behavior, the contribution focuses on the main requirements for developing user-specific mobile-navigation services. Subsequently, an approach to include landmark information in pedestrian-navigation systems via mobile phone is introduced. The approach concentrates on the identification of salient landmarks next to primarily observed main routes of pedestrian flows in a major train station and on the provision of spatial information via an audio-guiding system by the use of mobile phones.

Fig. 1. Landmarks can be remarkable objects which are situated either along (e.g., statues, also signposts), distant from the route (like the wall clock in this example), or a unique part of the route becomes a landmark itself (e.g., an escalator).

II. Human-Navigational Behavior

A person has several possible navigational strategies to find a desired goal [5].

1) The individual has no information and is forced to search randomly (random navigation).
2) The individual moves toward a visible cue, which leads to the arrival point (taxon navigation).
3) The individual follows a fixed motor program (praxic navigation, e.g., "turn left after 200 m, then turn right after 150 m").
4) The individual associates directions with visual cues (route navigation, e.g., "turn left at the church").
5) The individual forms a mental representation of the surroundings and is able to plan routes between any locations within the area (locale navigation).

Usually, an individual combines several strategies to optimize the wayfinding process. The chosen strategies often depend on the degree of familiarity with the surroundings. In many cases, navigational tasks are solved by the use of visual clues (landmarks) and by building a mental representation of the environment (e.g., by the help of maps).

In familiar environments, humans orient themselves and navigate through space with the help of "cognitive maps"—mental representations of the surroundings, which form a model of the world according to the way it is perceived by a specific individual. These mental maps are formed while walking repeatedly through an environment and memorizing more and more details of the surroundings.

Several authors in the field of spatial cognition assert that navigating humans rely on three forms of spatial knowledge: landmark; route; and survey knowledge [6], [7]. During the exploration of an unfamiliar environment, people first notice salient objects or structures at fixed locations. These unique objects or places are easy to recognize and can be kept in memory without difficulty. Landmark knowledge can, therefore, be thought of as a series of photographs. By and by, the better a person gets to know a particular area, the more routes between specific landmarks can be remembered. Route knowledge and landmark knowledge are both egocentric. Finally, growing familiarity with the environment leads to the development of survey knowledge. This special form of spatial knowledge is allocentric and enables an individual to estimate spatial relations between any arbitrary points within the familiar region. However, spatial knowledge develops individually and does not strictly follow the described stages. Furthermore, as metric configurational knowledge begins to be acquired as soon as a new environment is being explored, pure landmark or route knowledge usually does not exist [8].

Nevertheless, landmarks play a decisive role in human navigation. Landmarks are stationary, distinct, and salient objects or places, which serve as cues for structuring and building a mental representation of the surrounding area. Any object can be perceived as a landmark, if it is unique enough in comparison to the adjacent items (Fig. 1). The importance of landmarks for human navigation and wayfinding instructions is proved by a great amount of studies [9]–[12].

Landmarks are significant elements in the communication of route directions and part of mental representations of space. Local landmarks are either used at decision points, where a reorientation is needed, or they serve as route marks, as confirmation that one is going the right way. Distant landmarks, like mountains or large buildings, fulfill a compasslike role and are used for an overall guidance, as they can be seen from many points and greater distances [11].

The decision which objects or places of an environment are used as landmarks is influenced by many different factors. First, these objects or places have to possess a certain saliency, which makes them remarkable and distinctive. Therefore, the surrounding area determines the characteristics an object or a place must have to be perceived as a landmark (e.g., a multistory building is not unusual in urban areas but becomes a salient landmark when being situated in a rural village). Second, a person navigating through an environment has individual preferences when choosing landmarks. Women, for example, tend to select more three-dimentional objects like buildings or monuments for navigation, while men seem to prefer two-dimentional features like streets or squares [13]. The age of a person and especially social and cultural backgrounds also have great impact on the choice of specific salient features as landmarks [14]. Third, diverse modes of transport lead to a different selection of landmarks. Car drivers choose mainly adjacent objects belonging to the street furniture, caused by their accelerated speed. Pedestrians, on the other hand, are traveling slower; thus, they perceive more details and can notice objects located in greater distances to the path along which they are walking.

As the choice of effective landmarks has a great share in the quality of navigational instructions, the multiple factors of landmark selection have to be taken into account in the course of the development of pedestrian-navigation systems.

III. Analysis of Methods and Requirements for Pedestrian-Telematic Systems

A. Dataset Requirements

For several reasons, existing car-navigation systems are not suitable for the navigational needs of pedestrians.

As pedestrians are not bound to the road network in the way vehicles are, and they have more degrees of freedom in movement compared to car drivers. People on foot can walk in places where cars are not allowed to move, and they can always walk both directions on lanes and sidewalks and open areas such as squares, parks, or pedestrian's malls, which can be walked freely in any direction [15].

Furthermore, the accuracy of localization has to be higher for pedestrian needs. Positioning only by GPS appears to be insufficient, since an accuracy of 5–30 m is not satisfying for pedestrians [16]. Owing to "urban canyons" in inner city environments, the positioning process can suffer from shadowing effects and reflexions, and within buildings or underground stations, GPS localization is impossible at all. In general, basic satellite positioning has to be enhanced with advanced and assisted positioning procedures to reach satisfying accuracy. Methods to obtain the possibility to locate users in three dimensions with high precision need to be developed, combining GPS and GSM technologies, in addition to indoor positioning methods (e.g., transponders, beacons, Active Badge, Bluetooth, etc.). Especially, the localization of a person on the correct floor of a multistory building demands additional technologies [17].

Walking people cover smaller distances at a lower speed level; hence, they notice a lot more objects and details of the surroundings compared to car drivers. Landmarks are natural elements in human wayfinding strategies and should, therefore, be integrated in navigational services. These salient objects are easily recognized and remembered, so they enable people to find their way faster and more efficient than plain geometric information such as directions and distances would do, especially since the human capability to estimate metric distances correctly is rather poor and varies by individual.

B. Identification of Reliable Landmarks

To make landmarks available for routing instructions, the design of methods to discover appropriate landmarks automatically is required. Several different approaches deal with the problem of identifying reliable landmarks for pedestrian-navigation tasks.

One simple method to detect landmarks in spatial databases is to investigate existing digital topographic datasets using buffer areas along pedestrian routes [18]. However, as this method only gives information about existing objects near a chosen route, ignoring the actual visibility of the object as well as the salience of the landmark, additional methods to evaluate the uniqueness of an item have been prepared to identify appropriate landmarks. Some techniques analyze the visual attraction of facades adjacent to decision points [12], others compare the attribute values of data records (like the geometry of objects, buildings use types, building labels, etc.) and identify the most suitable landmark by ranking all attributes at potential decision points [19]. However, these systems disregard the fact that the visibility of an object is not invariable and that the quality of a landmark can differ, depending on the direction from which it is observed. To determine the visibility of an object, current approaches combine several methods to obtain salient landmarks by using data-mining processes and laser-scanning techniques to check the visibility of a specific object [20].

C. Route Qualities for Pedestrians

To provide efficient navigational information, a network of paths used by pedestrians has to be defined. This turns out to be a special challenge, as people often consider different "optimal" routes to reach the same destination. While car navigation systems usually offer information about the "shortest" or "fastest" route, pedestrian-navigation systems have to provide a greater amount of route qualities.

If a distance is covered afoot, the present attributes of a path are much more important than the properties of a route which is traveled by car. For example, safety is a quality often demanded, especially if a route has to be walked along in the evening. The disposition to walk a longer detour individually depends on a person's level of fear [21].

Routes, which are short in distance, can also be unattractive, if there are alternative routes which are less exhausting, as long as the additional distance is moderate. Particularly, routes inside a building are appraised differently according to the effort it takes to reach different floors: Elder people or persons carrying suitcases or similar things prefer to take an elevator or escalator, even if they have to walk a longer distance to reach it. In general, effortlessness is an important route quality for pedestrians, as it is not possible for some individuals (such as disabled people or persons with baby carriages) to walk certain sections of a path like stairways or steep rises. Recent research results show that people also prefer less complex routes to those routes, which are shorter in distance but contain a greater number of decision points [22] ("least-decision-load" strategy: Fig. 2).

Unlike car-navigation systems, pedestrian-navigation services have difficulties providing an "optimal" route suggestion to a traveler. The human perception of space differs in many ways, which provokes people to develop different strategies to solve a navigational task. Human spatial behavior is influenced by a great amount of factors, such as age, gender, social and cultural background, actual surroundings, etc. [14]. Therefore, it is difficult to constitute a network of optimal pedestrian routes. One possibility to discover routes which are preferred

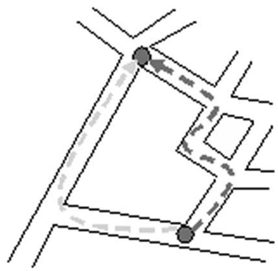

Fig. 2. Humans tend to minimize the complexity of a route leading to a desired arrival point and chose an alternative path containing a smaller number of possible movement decisions (left path), even if it forces them to walk a longer distance.

by an above-average amount of people is to observe pedestrian flows in order to recognize frequently used paths.

D. Future Research

The development of navigation systems requires future research in several fields of investigation. Dataset requirements include the design of pedestrian-route networks, the improvement of the accuracy of localization in mobile-navigation devices, and the integration of landmarks in route directions. The definition of pedestrian-route networks additionally requires the investigation of route qualities and the preference-specific groups of people show when choosing a certain route. The consideration of individual demands is difficult; therefore, methods to learn the preferences and spatial behavior of an individual will have to be developed.

Furthermore, the identification of landmarks is still the object of research. The introduced methods show some disadvantages, which future research is to overcome: Either the visibility of an object is not taken into account, or the potential landmarks are not investigated in respect of the uniqueness and salience of their appearance. Furthermore, although findings reveal that the quality of route instructions improves by inserting landmarks on nondecision points, which confirm the traveler to be on the right way [11], most methods for landmark detection rely on objects situated near potential decision points. Beyond that, present techniques to automatically identify landmarks concentrate on buildings, even though any object can serve as a landmark. Future methods will have to implicate other 3-D objects (like monuments, plantings, etc.) and 2-D elements of the route (such as distinctive squares or avenues). Signposts play a special role when being used as landmarks: Carefully designed signage systems can serve as distinctive, recognizable, and salient landmarks and provide additional information [13], [14]. Therefore, it is highly recommended for future pedestrian-navigation systems to refer to existing signposts when giving route instructions.

As the development of pedestrian-navigation systems still faces several challenges, the presented contribution describes a new approach, which tries to circumvent the main difficulties. The currently developed system avoids indoor-localization problems by identifying the position of a person by landmarks reported by the user himself. The generation of route descriptions refers to adjacent landmarks, taking into account the natural orientation behavior of pedestrians.

IV. Landmark Orientation via Mobile Phones

Although some research has so far focused on orientation and navigation of pedestrians and pedestrian crowds, further investigation of pedestrian-navigational behavior is still required, as past findings sometimes fail to explain certain phenomenon of pedestrian movements (e.g., what makes people use different routes to reach the same destination). Within the number of projects concerning pedestrian-navigation services, mainly the same technical approach as in vehicle-bound navigation (mainly satellite technology for positions) and PDAs/mobiles (geo-referenced maps for directions) have been used. Limitations of this approach were the precision of GPS and GSM positioning, the lack of cost-effective technologies to locate people within buildings [17], problems with the usability of human-machine interfaces [23], [24], and the small penetration rate of mobile phones with large displays and UMTS technology in Europe and the U.S.

Furthermore, the approach to guide pedestrians has not been varying from the car-guidance systems, which does not take the requirements for pedestrian navigation into account.

We intended to demonstrate and evaluate the functionality of a landmark-orientation system via mobile phones at a major train station in Austria. The voice-operated and landmark-based system is supposed to guide travelers through highly frequented transport infrastructure via their own familiar mobile phones, as opposed to provide people with extra devices for navigation. It aims at travelers that are either not familiar with the transport infrastructure (tourists and senior citizens), or offers guidance for everybody during reconstruction periods. The user calls a service number, identifies her position (e.g., entrance Underground Station) and her destination (e.g., Track 10), which is processed via a speech-recognition system, and is then offered a trail of landmarks that she can follow to reach her destination.

Unlike other models of pedestrian-navigation services, this system does not have to deal with the difficulties of indoor-localization techniques, as the position is identified by the landmarks reported by the user himself. Therefore, it is possible to use accustomed mobile phones, which minimizes the risk of low acceptance caused by technophobia.

The focus of the research lies in the recognition of landmarks, their description, and the definition of requirements for an automatic landmark choice in order to develop a prototype navigation system for pedestrians.

To develop a landmark-based navigation system, the following techniques have been applied: A video-analysis system has been temporarily installed in order to obtain and to analyze pedestrian trajectories. Then, inquiries were conducted to identify and categorize reliable landmarks along the main routes. Subsequently, based on the results of the previous surveys, a routing table containing all relevant origins and destinations within the research site was generated.

A. Vision-Based Analysis of Walking Behavior

In order to understand the walking behavior, the research site—a major Viennese station—was monitored for two weeks by a network of seven network surveillance cameras, providing

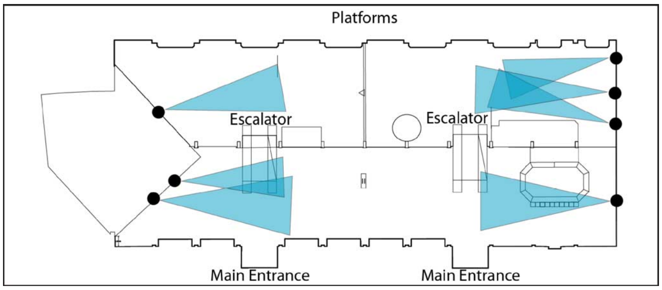

Fig. 3. Overview of camera positions on the floor plan of the train station.

Fig. 4. Typical frame from camera 1 containing tracked individuals.

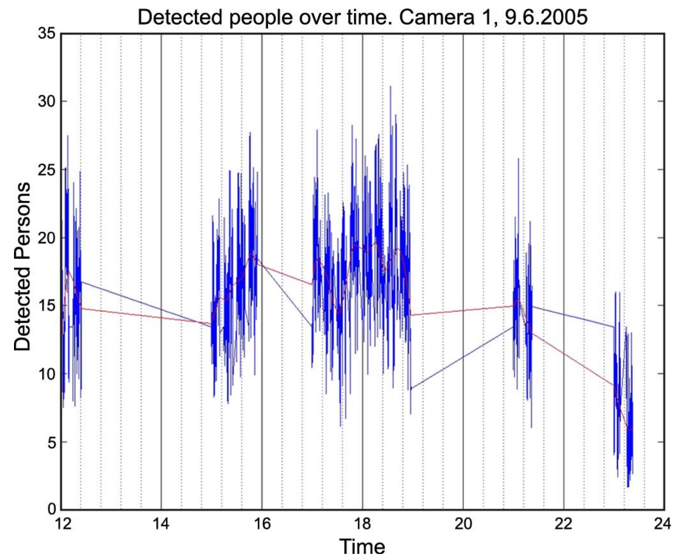

Fig. 5. Number of tracked people over time. Note that the "empty" regions are time intervals during which no recording of the video streams has taken place.

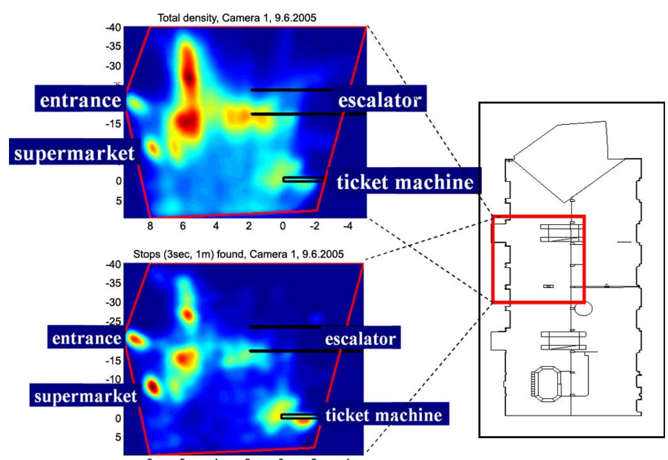

Fig. 6. Detected stops. (Top) All stops. (Bottom) Stops longer than 3 s (floor plan).

an output stream of approximately 25 JPEG-coded video-frames per second. The positions, fields-of-view, and orientations of the sensors have been determined *a priori* in order to assert maximal coverage of the interesting spots. Fig. 3 shows an overview of the chosen camera positions. The digital video streams of selected time intervals have been permanently stored for subsequent offline video analysis.

For every stored video stream, a state-of-the art visual people-tracking approach, being able to resolve mutual occlusions of a few persons [25], has been applied. Fig. 4 shows a typical video frame comprising the detected people in the frame as bounding rectangles and the people trajectories as colored lines.

People tracking produced hundreds of thousands of (partial) trajectories for the entire recording period. After a removal of obvious outliers (e.g., very short trajectories), a number of statistics have been computed on the trajectories transformed on the floor plan of the train station [26]. Fig. 5 shows an example plot for the number of tracked people between 12:00 A.M. and midnight. Peaks in Fig. 4 clearly indicate busy times during scheduled arrivals and departures of trains. Fig. 6 shows the detected stops over a whole day for different definitions of a stop (moving no more than 1 m during 2 s and 3 s). The areas of high stop density are at the ticket machine, at the escalators, and at the main exit where a newsman is located. However, less obvious stop clusters in front of a store are also visible. More information on this vision-based analysis can be found in [27].

B. Landmark Identification

The statistics of the people trajectories provide hints for highly frequented routes within the station and areas where people often change direction or stop helped to identify decision points.

The final landmarks have been determined by the researchers by asking test persons to identify salient landmarks on several pictures taken in the station as well as analyzing route descriptions given by test persons walking through the station. Landmarks on (potential) decision points next to the identified main routes as well as distant landmarks for overall guidance were defined, and clear understandable terms and descriptions were determined [28]. A survey of the identified landmarks and the main decision points can be seen in Fig. 7.

The results of this analysis provide the basis for the determination of navigational instructions.

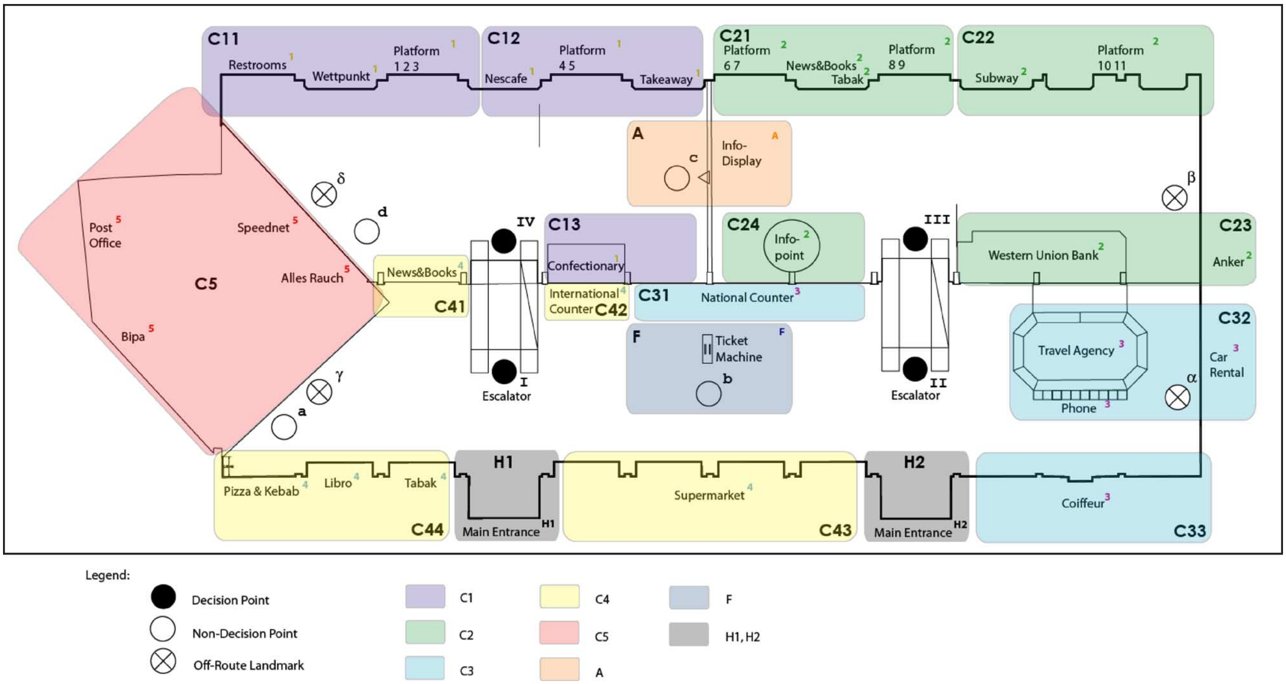

Fig. 7. Landmarks and decision points in the train station: Landmarks have been assigned to hierarchical classes, which are marked in color.

C. Creating Routing Statements

To generate routing instructions, the possible routes within the station had to be divided into sections, leading a navigating person from one salient landmark to the next until the desired goal is reached. However, using all sections to and from each of the 40 identified landmarks (and including four decision points) would have required an amount of at least $40 * (40 + 4) = 1760$ routing statements, so the number of sections has been reduced by assigning the landmarks to hierarchical classes. The major classes are marked in different colors in Fig. 6.

Based on the defined sections and the landmarks and decision points, a routing table was created to define navigational instructions from each origin in the station to each possible destination. Landmarks and wayfinding orders were represented with symbols in order to provide the necessary information for including the information into the audio guiding system. Table I shows a part of the routing table: Columns correspond to the origin landmarks and the decision points, and rows correspond to destination landmarks. The symbols represent codes providing the basis for the verbalization of oral wayfinding instructions.

D. Audio Guiding System

The identified landmarks and the defined route instructions are used to develop an audio guiding system based on commercially available speech-recognition and text-to-speech software. It is paramount that the audio guiding system employs verbalisms that are as distinct and clearly recognizable as the visual landmarks and that the users can intuitively combine the description with what they see. The development is continuously accompanied by usability studies in labs and questionnaires with control groups at the station.

TABLE I
ROUTING-TABLE FOR THE NAVIGATION BETWEEN LANDMARKS

		from			
to		C1	C2	C3	C4
	C11	↺δ ⌦	×δ c ⌦	×γ b I	…
	C12	↺β ⌫	×δ c ⌦	×γ b I	…
	C13	↺β ⌦	×δ c ⌫	×γ b I	…
	C21	×β c ⌫	↺δ ⌦	II	…
	C22	×β c ⌫	↺β ⌫	II	…
	C23	×β c ⌦	↺β ⌦	II	…
	C24	…	…	…	…

V. Conclusion

Landmarks play a vital role in human-navigation tasks. It is, therefore, necessary to develop methods to include landmark information in pedestrian-navigation services. The approach presented in this paper focuses on the identification of salient landmarks next to primarily observed main routes of pedestrian flows in an indoor environment and on the representation of landmark-based spatial routing information. It is paramount to understand that the major challenge in developing user-centered guiding-technology research in widely differing scientific areas has to be concerted.

The major challenges lie in the concept of landmark orientation itself and in the transfer from visually salient objects into navigational cues provided by spatial-information systems. The research process about quality criteria for landmarks is at a very early stage. The reliability of the chosen landmarks has to be determined by a quality-measurement system to avoid ambiguous landmarks that mislead the user. A system for qualifying landmarks has to be established to speed up future projects. Data-mining methods to provide a mechanism to automatically extract objects with a relative uniqueness in a given environment have been researched by several authors but are so far only working in outdoor surroundings.

To permit the constitution of efficient pedestrian-route networks, optimal route characteristics need to be clearly defined. Further research on the impact of individual factors, personal-navigation strategies, and environmental conditions on human spatial behavior is still requested, and main aspects causing differences in human route choice need to be identified in future research.

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