RouteCheckr: Personalized Multicriteria Routing for Mobility Impaired Pedestrians

Thorsten Völkel and Gerhard Weber
Human-Centered Interfaces Research Group
Technical University of Dresden
Nöthnitzer Straße 46, 01187 Dresden, Germany
+49 351 463 38477
{t.voelkel, g.weber}@hci-research.de

ABSTRACT
Mobility impaired people use a variety of assistive technologies to navigate independently in everyday life. Although several technical approaches for navigation systems exist, many drawbacks remain due to lack of geospatial resolution, inadequate geographical data provided, and missing adaptation of routes to a multitude of user specific criteria. We developed RouteCheckr, a client/server system for collaborative multimodal annotation of geographical data and personalized routing of mobility impaired pedestrians. The construction of algorithms supporting multiple bipolar criteria is described, applied to route calculation, and demonstrated in our university's campus. To satisfy individual requirements, user profiles are incorporated enabling adaptivity over heterogeneous user groups while preserving privacy. Finally, a general architecture for RouteCheckr is presented and simulation results are analyzed.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation (e.g. HCI)**]: User Interfaces – User-centered Design; K4.2 **[Computers and Society]**: Social Issues – Assistive Technology for persons with disability.

General Terms
Algorithms, Design, Human Factors

Keywords
Multicriteria routing, mobility impaired, multimodal annotation.

1. INTRODUCTION
Navigation systems have been widespread over the market, becoming an affordable mass market product. Navigation systems are mainly used for car navigation and have become miniaturized and portable. Additionally, navigation software is available for many mobile devices capable of using GPS sensors for positioning. Consequently, usage of navigation systems has broadened to other applications such as navigation support for cyclists and pedestrians. Particularly, the group of mobility impaired pedestrians including motor impaired, elderly people as well as blind and visually impaired people may benefit greatly from the use of navigation systems as an increased mobility would permit greater autonomy and independence regarding tasks and activities of daily life. However, only minor adaptations of mobile services have become available to satisfy requirements of pedestrians and particularly requirements of mobility impaired pedestrians. Such requirements include the provision of supplemental points of interest and specific geographic map data usable for the calculation of optimized and suitable routes as well as the generation of other than turn-by-turn navigation instructions.

For visually impaired and particularly for blind pedestrians, safety is one basic requirement as many try to avoid big, crowded, and noisy cross-ways and would thus accept a longer but safer route [22]. Consequently, safety is one important criterion for visually impaired people regarding suitability of routes. As safety ratings are not included within standard map data, they must thus be acquired to be considered for route calculation. Wheelchair users are also often guided along inaccessible routes including high curbs or stairs leading into dead ends [13]. Considering additional parameters for route calculation would clearly be beneficial for all of the named user groups.

As the acquisition of additional geographic data by public authorities or private companies is very cost-intensive, alternative concepts and methods are needed. We thus developed the concept of multimodal annotation of geographic data. The method enables mobility impaired pedestrians to annotate existing geographical data with their own information such as specific points of interest, environmental features usable for orientation, the location of obstacles, or specific safety and convenience ratings. As a novelty, additional data can be shared anonymously among predefined user groups to broaden map data available to each individual user. Building on already conducted research [21, 22, 23] we further elaborate the potential of multimodal annotation of geographical data by discussing modifications of well-known navigation algorithms within this paper. Standard route calculation algorithms are enhanced to incorporate multiple criteria when determining optimized routes. Furthermore, it will be shown how personalization can directly be realized by applying user profiles which are adaptable by the user. Finally, results of preliminary simulations are presented and discussed.

The paper is structured as follows. Section 2 contains a detailed descriptions of the problem discussed throughout the paper as well as a broad overview of related work in the field. The concept of multimodal annotation of geographical data is briefly introduced in section 3 including a discussion of requirements imposed by mobility impaired pedestrians. Section 4 includes a detailed description of strategies used for personalized multicriteria routing which lead to the presented algorithm. A

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general client/server architecture for RouteCheckr and simulation results of our server implementation as well as of our routing engine are then presented in section 5 followed by a conclusion and an outlook in section 6.

2. PROBLEM STATEMENT AND RELATED WORK

Most drawbacks of currently available navigation systems are due to inadequate map data which are obtained mainly for car navigation. For example, specific paths which are only traversable by pedestrians are rarely included. Common route calculation algorithms are optimized regarding only one criterion, namely either route length or traversal time. Additionally, most systems only provide turn-by-turn instructions in conjunction with a flat two-dimensional and rather abstract graphical presentation of the map.

Although the cited drawbacks restrict the use of current navigation systems for pedestrians, most users are able to compensate them. users are able to use their vision to compensate inaccuracies and ambiguities regarding map data and navigation instructions. Users may for example use optional pedestrian crossings hence they are adjusting the route computed by the navigation system. However, many mobility impaired pedestrians are neither able to conduct such adjustments nor do currently available navigation systems fulfill additional requirements imposed by this user group.

Travel aids and assistive technologies for pedestrian navigation have been studied intensively since the 1980s. Initial work regarding travel aids for visually impaired pedestrians include [3, 11] as well as prototypes such as the MOBIC system [20], Drishti [6, 16], or the navigation system developed by projects Pontes and Odilia [15]. The MOBIC system also offered a pre-journey system for route planning and exploration. A pre-journey system is one important feature for pedestrian navigation systems but lies outside the scope of the research discussed in this paper. Even commercially available navigation systems specifically developed for visually impaired user such as Humanware's Trekker [8] or Sendero GPS [17] use map data previously optimized for car navigation. Although map data is adapted by these systems to fit basic requirements of pedestrians, route calculation is only optimized regarding absolute length. Regarding the group of wheelchair users, design considerations for navigation systems have been presented by Ding et al. [3] indicating that routes for wheelchair users should also be optimized regarding structural accessibility.

Although promising results have been achieved, such as the construction of accessible user interfaces for mobile devices, major problems remain unsolved. We are investigating the acquisition of additional geographical data and its utilization to provide optimized and personalized navigational support for mobility impaired people. One approach attracting increasing attention within the research community is the incorporation of actual users for the acquisition of such data. This approach seems particularly promising as studies reveal that perception regarding obstacles and accessibility of route sections differs significantly between disabled and non disabled pedestrians [24]. As a consequence, much research has been conducted lately aiming at developing concepts for user-driven map annotation as well as at developing routing methods utilizing the acquired data.

A first prototype of a navigation system particularly designed for wheelchair users has been developed by Kurihara et al. [10] where users are able to collect data indicating the accessibility of path sections. This data is then used to calculate optimized routes with respect to the individual abilities of the user. A similar approach is followed by Holone et al. [18] allowing physically handicapped users to rate the accessibility of locations using a tripartite rating system. Gathered annotation data can be shared among user groups, although data between different user groups is not shared. Both methods use the criterion accessibility in addition to length for route calculation. However, a general methodology for incorporation of an arbitrary number of criteria has not been developed. Additionally, a personalization of route calculation is only marginally realized. Kurihara's system allows the user to choose one of three predefined capability categories which consequently limits the incorporation of individual preferences. In contrast, Holone's system allows the user to select a user group from which additional data about accessibility of locations is acquired which is then incorporated during the route calculation process. However, only the last accessibility rating is used for calculating the cost for a given route section. Consequently, malicious user ratings cannot be compensated by other ratings. Furthermore, individual preferences are not directly considered.

Pedestrians and particularly mobility impaired pedestrians are very heterogeneous regarding physical abilities and preferences. Beyond the shared interest in data about structural barriers, further concepts are needed for incorporating more individual criteria within the route calculation process as well as applying personalization strategies. Within the following sections we thus discuss a new method for applying geographic data acquired by users of navigation systems within personalized route calculation processes. Our concept proves flexible as an arbitrary number of criteria can be used within the route optimization process and personalization is achieved by incorporating user preferences gathered from direct user feedback.

3. MULTIMODAL ANNOTATION OF GEOGRAPHICAL DATA

The concept of multimodal annotation [21] is based on two integral parts, namely direct annotation of geographical data by users and acquisition of directly observable information which is derived from analyzing the user's LOM-Modality. The LOM-Modality integrates the user's location, orientation, and movement into one modality (for details see [23]). Examples for direct user input include ratings regarding diverse criteria such as safety or general convenience. Additionally, environmental information such as the slope of a path section, specific points of interest, obstacle locations, small sound samples and even images can be gathered. Traversal frequencies and the time needed to pass specific routes are examples for directly observable information. For instance, a high frequency of traversal of people belonging to one user group might indicate a higher suitability of related routes compared to other routes with lower frequency.

To gather additional requirements, we conducted a survey including 88 visually impaired and blind respondents. As respondents represent only one group of mobility impaired pedestrians, requirements for other groups have been gathered by extensive literature review. The results and implications are discussed only briefly here as details have been previously published in [23]. Respondents were asked whether they would use specific features if provided by navigations systems allowing for extending map data with own information. The great majority of 75% confirmed to provide such features if used by the system. Besides the need to provide specific orientation information and the need to incorporate additional criteria for route calculation, one of the main results of the survey is given by requirements regarding the annotation process:

- Annotations must preserve temporal correlation as geographical entities and annotations may be due to change over time. For example, construction sites and road works are obstacles which affect the accessibility of a location only for a specific time. Additionally, annotations may only be valid for specific environmental conditions, i.e. illuminated advertising is only useful for orientation if light conditions are appropriate. Another example is given by annotations regarding the condition and structure of the underground. Conditions may change due to environmental effects such as leaves or snow covering the ground. Temporal coherence also has an impact on weighting of an annotation as newer annotations and ratings might reflect actual conditions more accurately (see section 4.3 for details).
- Annotations must preserve a relation to the user group of the annotating user. Survey results indicate that significant differences regarding the use of environmental information for orientation exist even between the groups of visually impaired and blind pedestrians. However, analogies have been identified indicating that some annotations can also be shared between multiple user groups.
- Annotations must preserve spatial relations which can be derived from the analysis of the LOM-Modality. Besides the pure location of an annotation, information such as the orientation or the movement of users is important. For instance, the usage of photos for navigational instruction is not possible without knowing the exact perspective necessary for guiding a pedestrian.

Annotations can basically be used for two purposes, namely multicriteria route calculation and generation of other than turn-by-turn navigation instructions: User ratings as well as directly gathered information from the analysis of the user's LOM-Modality can be incorporated within adaptable routing algorithms to optimize a route with respect to multiple criteria. Regarding the provision of additional navigation instructions, consider the annotation of the map data with photos of landmarks. The provision of such visual instruction has proven to be significantly more effective for pedestrians [1] and particularly for elderly people [5] compared to the use of pure paper-based maps.

The conceptual framework of multimodal annotation of geographical data incorporates strategies for sharing annotations among user's of the same user group. As the association only relates to the user group, no relation of data and user can be reconstructed, hence basic privacy requirements are ensured. However, a traveler navigating in an environment unknown to him is then able to access additional information which can be integrated to broaden the map data of the navigation system used.

4. MULTICRITERIA ROUTING STRATEGIES

4.1 Static Multicriteria Routing

Within this section we describe personalized multicriteria routing and modify Dijkstra's algorithm [2] as one well-known standard routing algorithm. We elaborate the construction of the concept by discussing an example based on the simple graph shown by Figure 1:

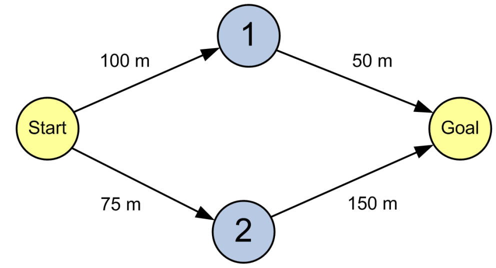

Figure 1: Simple navigation graph

Navigation algorithms use cost functions to determine the cost of a given route. For determination of the shortest route, the cost function simply sums the lengths of all sections of a given route. In general, the shortest route is calculated by solving the corresponding minimization problem. To solve this problem, common shortest path algorithms use iterative strategies based only on local information about adjacent path sections. Regarding the above example, the route via node 1 would satisfy the requirement of minimized length as its cost is 150 compared to 225 of the route via node 2.

As mentioned before, mobility impaired pedestrians impose additional requirements upon the calculation of suitable routes. In particular, an optimized route must be compliant with potentially diametrically opposed requirements. For instance, the optimization of a route regarding the two criteria safety and length is conflicting as the shortest route might not be the safest and vice versa. Consequently, strategies are needed to determine a route which optimizes all required criteria but as well allows a compensation of one criterion by another. In other words, a cost function is needed allowing determination of the best balance between all required criteria. Criteria values such as accessibility ratings or safety ratings might not be available for all necessary path sections. The network must thus be initialized with specifically marked default values. We use the most pessimistic rating for initialization leading to improved ratings when user annotations become available. This strategy directly implies that sections traversed by users might be more suitable than non-traversed sections.

In general, a vector of criteria values is assigned to each path section. To calculate the cost for each path, a cost function must be determined which allows for a comparison of sections as well as for a comparison of paths consisting of multiple sections. Following approaches used in the field of multicriteria decision making [9], we use a cost function that is based on weighted addition. This approach is particularly beneficial as a linear coherence between all criteria values is preserved. For the general case, such a cost function is given by equation (4.1). Let S denote the number of criteria values, ω_i the weighting for criterion value c_i, ω_j the rating for r_j and given the conditions $\sum \omega_i = 1$ and $\sum \omega_j = 1$. The multicriteria cost C_{Path} for a path is then calculated as follows:

$$C_{Path} = \sum_{i=1}^{S} \omega_i c_i, \quad \text{where } c_i = \sum_{j=1}^{N} \omega_j r_j \qquad (4.1)$$

A criterion value c_i may itself be calculated as a weighted average of N single criterion values if multiple path sections are considered (see equation 4.4 for an example calculation). The presented approach only allows compensation between different criteria if the corresponding values are normalized to one scale. Before discussing personalization issues in detail, we calculate multicriteria costs for the example shown in Figure 2. Two criteria are used: safety which is denoted by the first vector entry and length denoted by the second. The values of the safety rating range from 1 to 5 where 1 is best (this range is explicitly chosen to enable usage of 5-point Likert scales for personalization, see section 4.2 for details). To calculate the cost for a section, length values must be normalized to the scale used by the safety ratings.

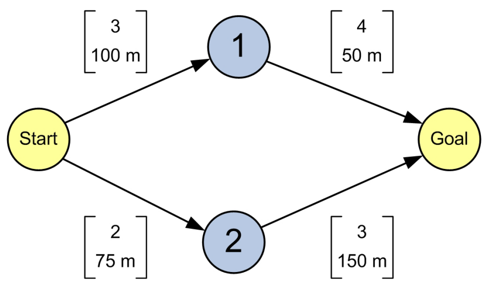

Figure 2: Graph with multiple weights

As shortest path algorithms step by step follow the most promising section until the goal is reached, normalization must be conducted within each iteration to enable comparison of all candidate sections. The cost calculation must be modified to include multiple criteria whereas the remaining parts of shortest path algorithms are not modified.

Regarding our example, the first two candidates are given by the sections from start to node 1 and node 2 respectively. The first step includes normalization by the following strategy. The highest value is associated with the worst cost of 5. All other values are then assigned proportional costs as shown by Figure 3.

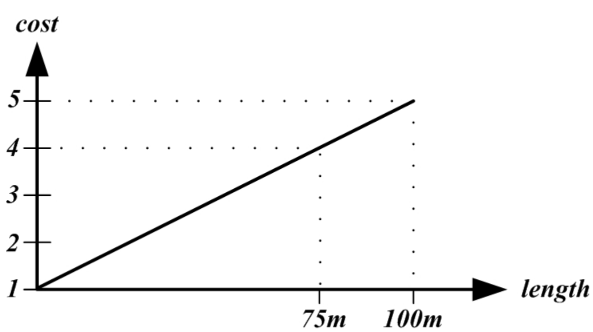

Figure 3: Normalization of length values

The applied strategy ensures that proportions between values are maintained when normalization is conducted. Applying an equally weighted addition (weights are 0.5), costs for the two candidate sections are calculated as given by equation (4.2) and equation (4.3).

$$C_{Start,1}^{cost} = 0.5 \cdot 3 + 0.5 \cdot 5 = 4 \qquad (4.2)$$

$$C_{Start,2}^{cost} = 0.5 \cdot 2 + 0.5 \cdot 4 = 3 \qquad (4.3)$$

The cumulated cost $C_{Start,2}^{cost}$ for the section to node 2 is well below the cost $C_{Start,1}^{cost}$ for the section to node 1 as both criteria are below their corresponding counterparts. For the second iteration, candidates would be the section from start to node 1 as well as the complete path from start to goal via node 2. Again, normalization must be conducted whereas the new maximum value would be given by the length of 225 m of the path via node 2. Considering multiple path sections, already scaled ratings must be cumulated to one value. The cumulated value is calculated by the average of the individual ratings considering the proportions of corresponding section lengths. Consequently, the safety rating $c_{Start,2,Goal}^{Safety}$ for the path via node 2 is calculated as given by equation (4.4).

$$c_{Start,2,Goal}^{Safety} = \frac{75}{225} \cdot 2 + \frac{150}{225} \cdot 3 = 2.67 \qquad (4.4)$$

As the second candidate path to node 1 only consists of one section, no average safety rating needs to be calculated. The section to node 1 would now be considered the most promising candidate, as its cumulative cost is $C_{Start,1}^{cost} = 2.69$ compared to $C_{Start,2,Goal}^{cost} = 3.84$ for the section via node 2. Finally, the third iteration consists of a comparison between both complete paths via node 1 and node 2 respectively. Costs $C_{Start,1,Goal}^{cost}$ and $C_{Start,2,Goal}^{cost}$ are resulting in 3.33 for the path via node 1 and 3.84 for the path via node 2. In summary, using both criteria with equal weighting, the shorter path is considered better although its mean security rating is lower compared to the mean security rating of the path via node 2. Costs associated with criterion length thus overcompensated comparatively higher costs imposed by the security rating.

4.2 Personalized Multicriteria Routing

The approach using equally weighted and normalized criteria values is rather static and does not consider any user requirements. Considering only the group of blind pedestrians, great differences exist in terms of mobility and individual preferences. Consequently, personalization issues are very important regarding the rating of different routes. Our concept for personalization of multicriteria routing is mainly based on the provision of predefined user group profiles which can be adapted by the user.

Adaptation by the user is realized by providing 5-point Likert scales, one for each criterion to be rated regarding its individual importance. Dependent on the user's rating, each criterion is assigned a value between 1 and 5 whereas 5 is the highest rating. To reflect the user preferences within the calculation of route costs, ratings are correlated with weights of corresponding criteria as shown by Figure 4.

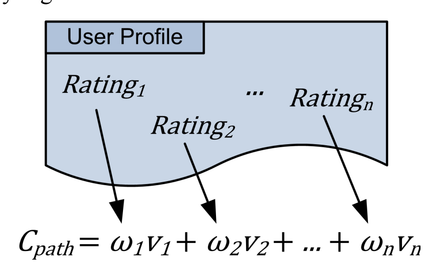

Figure 4: Correlation between user profile and cost calculation

Before criteria ratings can be used within the cost function, a conversion must be conducted as the initial scale for all ratings is not applicable. The condition of $\sum \omega_i = 1$ must be considered. Let r_i be the value of the i-th rating out of a total of n ratings. The calculation of the corresponding weight ω_i is then conducted as given by equation (4.5).

$$\omega_i = \frac{r_i}{\sum_{j=1}^{n} r_j} \quad (4.5)$$

Considering the above example with associated criteria length and safety, a user might rate the importance for length with a value of 1 and the importance of safety with a value of 3. The user's preference clearly tends towards safety as its rating is three times higher compared to the corresponding rating for the criterion length. The weights for safety and length are consequently $\omega_S = 0.25$ and $\omega_S = 0.75$. Equations (4.6) and (4.7) show the calculation of the cost for both paths via node 1 and node 2 respectively.

$$C_{S,1,G} = \frac{150}{225} \cdot 5 \cdot 0.25 + \left[\frac{100}{150} \cdot 3 + \frac{50}{150} \cdot 4\right] \cdot 0.75 = 3.33 \quad (4.6)$$

$$C_{S,2,G} = \frac{225}{225} \cdot 5 \cdot 0.25 + \left[\frac{75}{225} \cdot 2 + \frac{150}{225} \cdot 3\right] \cdot 0.75 = 3.25 \quad (4.7)$$

In this example, the user raised the rating for criterion safety. Consequently, its impact regarding the final result is significantly higher. According to the user preferences, the route via node 2 is associated with less cost compared to the route via node 1 thus compensating the drawback of its higher length.

Although our example only contains two criteria, the strategies introduced so far are also applicable for an arbitrary number of criteria. Examples include convenience ratings of users of the same user group as well as the number of environmental features which could be used for orientation. However, a usable system should limit the number of criteria, as otherwise the influence of the user's rating for one criterion decreases. Consequently, a change of one rating might not result in any adaptation at all.

4.3 Time-Dependent and Stereotype-based Collaborative Annotation

Multimodal annotation of geographic data enables collaborative acquisition of additional environmental information. User annotations can be shared via a central server synchronously and asynchronously. Collaborative strategies for data acquisition offer many advantages as users are able to provide information about their well-known environment while also benefiting from data about unknown areas acquired by other users. However, such strategies also raise specific problems as listed below:

- Annotations reflect the individual perception of the annotating user. Accordingly, other users may experience environmental conditions differently.
- Collaborative strategies benefit greatly from multiplicity of individual contributions but are also vulnerable to malicious contributions.
- Annotations represent the actual condition of the environment and the actual experience of the user respectively. However, environmental conditions are due to change over time.

Annotations are dependent on the actual user's perception and rating of environmental conditions. Additionally, the perception of environmental conditions differs greatly between different users even within the same user group [22]. Linking annotations to a user group is necessary to ensure basic applicability for other users. However, partitioning of given user groups might be necessary to comply with preferences of individual users.

Collaborative strategies enable a distribution of the effort necessary to gather extensive data sets. However, collaboration relies heavily upon reliability of contributing users and contributed data. As a complete prevention of malicious annotations is not realizable, strategies must be applied ensuring a minimal impact of such annotations. Consequently, ratings of users differing significantly from expected ranges should be weighted less when calculating mean values.

Environmental conditions are due to change over time as for instance inaccessible structures for wheelchair users might be removed or orientation features for visually impaired pedestrians such as tactile guide strips might be added. User ratings thus continuously reflect the change of the environment either positively or negatively. Considering a single path section, different users might provide accessibility ratings which must be consolidated to one single value to be used within the presented multicriteria route calculation methods. A naïve approach of calculating the simple mean value of all ratings does not consider any changes which might occur over time. As a consequence, temporal considerations must be incorporated. We therefore propose an alternative approach implicitly incorporating changes over time. Figure 5 shows the schema used for determination of rating weights dependent on the actual annotation time. The upper part of the diagram demonstrates ratings r_1 to r_{11} with their corresponding annotation times. The lower part represents a function assigning a weight to each individual point of time.

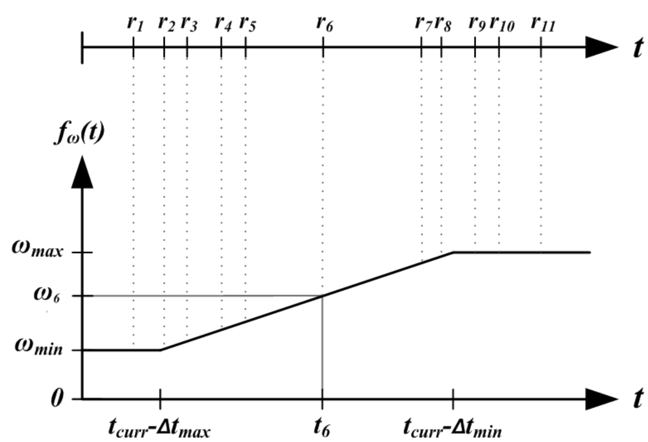

Figure 5: Determination of annotation weights with respect to annotation times.

The weight ω_i for rating r_i is given by the corresponding function value $f_\omega(t_i)$ for annotation time t_i. An example is emphasized for rating r_6 and its corresponding weight value ω_6 for t_6. Generally, the function ensures that the more the annotation of a rating dates back, the lower its corresponding weighting will be determined. However, two bounds are applied, namely the lower bound t_{curr}-Δt_{max} from which weights are increased linearly until the upper bound t_{curr}-Δt_{min} is reached. Both bounds are adapted dynamically as they are calculated by subtracting given offsets Δt_{min} and Δt_{max} from the actual time Δt_{curr}. Ratings older than indicated by the lower bound are constantly assigned the minimum weight ω_{min} and ratings with an annotation time after the upper bound are constantly assigned ω_{max} respectively. A time-dependent rating value is then calculated as given by equation 4.8:

$$R_{avg} = \left(\sum_{i=1}^{S} \omega_i r_i\right) / \left(\sum_{i=1}^{S} \omega_i\right) \qquad (4.8)$$

The presented approach offers many advantages compared to rather static approaches such as presented in [7], where only the maximum value of all annotated ratings or the last rating is used. Our approach enables the calculation of a dynamic time-dependent weighted average rating which additionally considers changes over time. For example, a path section undergoing structural modifications regarding its accessibility will thus continuously gain better ratings. These new ratings are then incorporated using a higher weighting than older ratings which might not reflect the current conditions properly. Additionally, as a weighted average is applied, malicious ratings have a decreasing impact the more ratings are acquired and the more such malicious ratings date back. Further algorithmic adjustments regarding the reduction of malicious ratings may include a decreased weighting for ratings differencing significantly from the expected value. Such a value may be calculated as the simple average of all ratings within a specific time interval around the actual annotation time.

5. SYSTEM DESIGN AND EVALUATION

5.1 General System Architecture

Within this section the general system architecture of RouteCheckr is described to illustrate the realization of concepts discussed above. The system consists of two integral parts, namely a central server and mobile clients used by users of the system. Figure 6 shows the architecture of the proposed client/server system.

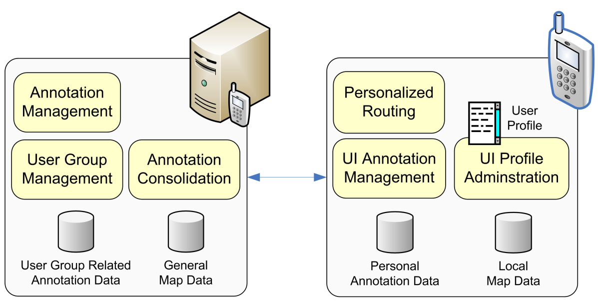

Figure 6: General system architecture

The RouteCheckr server can be implemented using standard server technologies such as J2EE and essentially incorporates three central components besides the provided databases:

- *Annotation Management*: This component is responsible for administrating the annotation data and for the provision of basic services for clients regarding submission and retrieval of annotation data.
- *Annotation Consolidation*: This component is responsible for consolidating annotations and ratings to values fitting into a given scale. For instance, safety ratings annotated by various users at different times must be consolidated to one value for each corresponding path section. This component could also be implemented on the client.
- *User Group Management*: This component is responsible for maintaining user group profiles which are necessary for the provision of standard parameters such as information about inaccessible environmental structures specific to the user group.

The client possesses the user profile of the user which is necessary to conduct actual personalization for the multicriteria route calculation. In particular, the client incorporated the following central components besides the provided databases:

- *Personalized Routing*: This component is responsible for determination of routes with respect to multiple personalized criteria.
- *UI Annotation Management*: This component provides an accessible user interface for acquiring and storing personal annotation data as well as for interchanging annotation data with the server. As client data will only be related with the user group of the annotating user, basic privacy requirements are satisfied.
- *UI Profile Administration*: This component provides an accessible user interface for administrating the actual preferences of the user.

Communication between client and server is realized via standard GSM/UMTS channels enabling the provision of a transparent IP-based transport. The client component can be realized on standard mobile hardware such as currently available Symbian-bases mobile phones or smart phone. Regarding the user interface, basic accessibility requirements must be satisfied such as the provision of non-visual interaction capabilities and adaptable presentations regarding for instance font size and contrast. In particular, the user interface must comply with commercially available screen readers for mobile devices such as Nuance Talks [14].

5.2 Prototype Evaluation

We built a prototype for first evaluation of the described algorithms. The prototype mainly represents the server part of the RouteCheckr system. We implemented our multicriteria routing algorithm within the server part to enable simulation although this component should conceptually be integrated within the client implementation. The server is based on the Spring J2EE framework [19] enabling flexible component-based development. Georeferenced map data is stored within a relational database and has been bought from the local land surveying office for the university campus as well as for the area around the main railway station. Although map data has been acquired in digital format, additional manual preprocessing had to be conducted to create a navigable network that includes sidewalks and footpaths. Figure 7 shows part of the university map with overlaid path network.

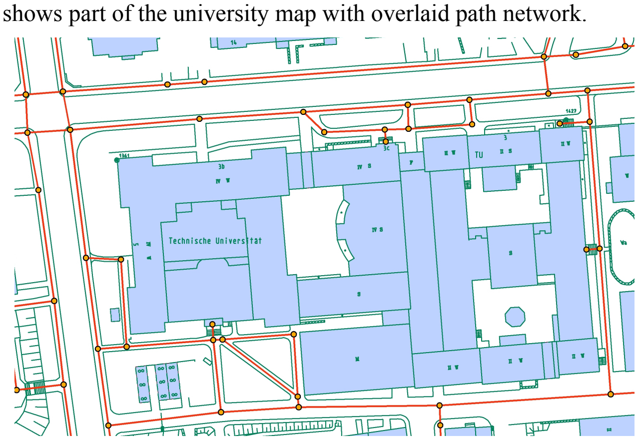

Figure 7: Part of the university map with overlaid network

Additional components such as user and user group administration have been implemented strictly following principles of component-based and object-oriented software design. Our personalized multicriteria route calculation algorithm has been implemented in a separate component as the component will be integrated within the client in the next version of the RouteCheckr software system.

For simulation purposes, a GUI framework has been implemented allowing for an easy adjustment of user profiles, user group profiles and annotation data. Figure 8 shows a screenshot of the main MDI-window of our simulation environment including the panel for simulating route calculation (left) and the network rendering panel (right). Additionally, panels for administration of users, user groups, and annotations are available. The route calculation panel allows for selection of the user and the declaration of start node and end node. Additionally, navigation algorithms can be selected allowing for direct comparison of different implementations. The network panel allows for zooming and access to specific data such as annotations and attributes associated with nodes and arcs of the network. The network panel shows results of route calculation by colorizing the calculated path and displaying basic properties such as path length and path cost.

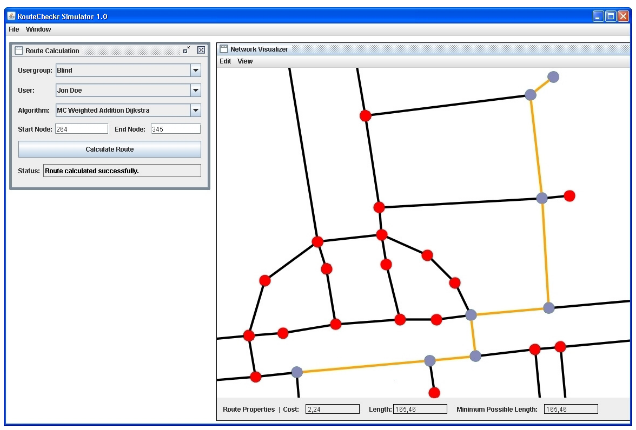

Figure 8: Screenshot of our simulation environment

Using our simulation environment, we particularly analyzed the interrelation between user profile, annotation data and calculated route. We used heuristically acquired annotations for two routes within our map data for the groups of blind pedestrians and wheelchair users respectively. Criteria length and security were used for the first group, criteria length and accessibility for the latter. Variations of the corresponding user profiles allowed for compensation of criterion length by criterion security and accessibility respectively. We particularly found that the linear correlation of criteria costs provided by the presented algorithm seems to adequately reflect user expectations at least regarding our test area; safer routes lie well within the maximum acceptable detour of 500 to 1000 meters stated by respondents of our survey. Additionally, route calculation is comprehensible in terms of strategies involved (a higher security / accessibility requirement generally leads to a longer route).

6. CONCLUSION AND FUTURE WORK

Within this paper, LOM-Modality has been integrated with user data for annotation of geographical data. For instance, location is reflected in obstacles, orientation contributes to time for movement (for example slope dependent wheelchair user's time) and all movements are subject to user annotations as well as distance measurements.

Principles of an algorithm for personalized multicriteria route calculation are presented. The algorithm uses additional data acquired using the method of multimodal annotation of geographic data. We consider individual preferences and temporal relations of annotation data. One of the main advantages is given by possible compensation of bipolar criteria regarding the rating of different routes. This compensation is directly affected by the profile of the actual user enabling incorporation of individual preferences. First simulations reveal that resulting routes are comprehensible and adequate regarding length of corresponding detours. However, some hypotheses have been developed during system implementation and simulation which require further investigation and forthcoming trials to be conducted with a range of mobility impaired users:

- *Limitation of criteria*: Users are able to directly influence route calculation by rating different criteria using a 5-point Likert scale. However, user profiles should be limited to a small number of criteria, most likely to three or four criteria, as otherwise variation effects of criteria ratings are no longer comprehensible. For instance, a user profile for blind users might include criteria length, security, number of orientation features, and overall user rating of blind users. A general convenience rating might as well be calculated of multiple data sets such as traversal frequency and mean time necessary for traversal.
- *Interrelation between user groups*: Currently, annotations are directly related with the annotating user's group. However, specific annotations are very likely to be suitable for different user groups. For example, the position of lowered curbs might be annotated by a wheelchair user indicating accessibility. In contrast, this annotation has a negative implication for blind pedestrians as lowered curbs might not be sensible tactilely. Another example is given by accessibility ratings acquired from wheelchair users which can also be important information for elderly pedestrians using a walker.
- *Convergence of annotation data*: Regarding the concept of time-dependent collaborative annotation and the presented algorithm, we presume a convergence of consolidated values for annotations. Considering for example safety ratings acquired by blind users, the consolidated safety rating will very likely converge to one fixed point given no environmental changes occur. However, future work may include evaluation of other approaches to achieve faster convergence and greater robustness regarding malicious annotations.

General concepts and methods for personalized multicriteria route calculation have been discussed intensively. Future work regarding the extension of the presented algorithm includes incorporation of thresholds such as maximum detour length acceptable by the individual user. Building upon the theoretical basis, future work will also include conduction of user trials. We are currently planning user tests to evaluate user behavior regarding the annotation process as well as regarding the actual usage of annotations for route calculation. User tests should particularly reveal, whether our assumption in terms of comprehensibility also holds for real users. These tests will have to show a sufficient number of annotations will confirm participants who participated in our requirements study [22] and lead towards better routing of mobility impaired pedestrians.

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