WALKWAY NETWORK BUILDING FOR MULTI-MODAL ROUTE PLANNING

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ABSTRACT:

Most of public travel information services nowadays are limited to the driving navigation or bus/subway guidance. Practical needs for pedestrian navigation yet haven’t got met enough and usually result in unacceptable travel route planning. This paper presents an approach on building Walkway network with different map layers for pedestrian specified facilities, and then implements pedestrian aimed route planning considering complete walking guidance. With the road network dataset and the walking concerned facilities dataset (e.g. overpass, underpass, pedestrian crosswalk in separate map layers), this research established a walkway network automatically through neighbourhood searching, topological and geometrical computation, as well as attribute considering. The walkway network is argued suitable for foot walking and critical for the walking guidance during mode transfer in multi-modal journeys, and also the fundamental difference with traditional approaches and current map websites and mobile navigation systems. A prototype system was developed to verify above approach. Data utilized in this prototype comprise detailed road network navigation dataset, and overpass, underpass and pedestrian crosswalk dataset in Beijing downtown.

1. INTRODUCTION

The rapid population expansion during past decades has greatly promoted the increase of travelling activities involving different transportation modes besides walking (Hochmair 2007). Tremendous daytime transit in urban area occurs almost every day in great metropolitan, which actuates not only transit operators but also web services operators to engage in providing travel information service (EU-Spirit 2006; Google 2009).

In the past decades, multi-modal, multi-criteria route planning (MMRP) has absorbed much attention. However lacking essential Walkway network is a reality for most route planners, especially for web-based applications. Transport for London (2007) is a multi-modal, multi-criteria, and multilingual route planning system, with stairs, escalators or lifts information yet without spatial location. Metro Trip Planner (2008) may indicate the number of parking place, elevator or escalator nearby, but without location information neither. Plan Your Trip with the RTA (2008) provides transfer with only walk direction. Other systems such as San Diego Metropolitan Transit System (2007), SCOTTY (2009), Bayerninfo(2009) have the similar problem. Without spatial information, all the above systems can hardly provide feasible guidance for the travellers once mode change happens.

Pedestrian navigation, well studied in individual guidance for the disabled and turn-by-turn instructions, is the most appropriate inter-modal connection approach. Presently temporary virtual links on road network for walking guidance is the common solution for inter-mode transfer. Google Map (2009) and EU-Spirit (2006) provide multi-modal route information but ignore the pedestrian facilities, and the walk guidance even has the same limit orientation as driving network. Google Map has specifically pointed out “this route may be missing sidewalks or pedestrian paths”, which may not guide travellers to their destinations successfully, especially in unfamiliar areas or areas with sophisticated transport facilities. Foo et al. (1999) presented an algorithm to solve MMRP problem with adding walking edges dynamically when a certain point is not in the stop set. Booth et al. (2009) utilized edges to describe pedestrian mode and to represent intersections. The edges involve roads, additional pedestrian pathways, and even the sidewalks between bus stops. However, the edges must exist and have been a part of road network. Lo et al. (2005) offers an interactive way for multi-modal route planning with state augmented multi-modal network. As for walking path, it adopts the same approach as Foo’s. This approach is viable under simple situation, when it comes to more sophisticated one, such as the road network with many crossing barriers, pedestrian overpasses, underpasses, it would not work well.

PDA or smart-phone based on-trip pedestrian assistant is a popular product and useful for travellers. Karl et al.(2007) designed a prototype of a digital personal travel companion for multi-modal journeys. It could provide accurate pedestrian navigation in complex public transport transfer buildings. Rehrl et al. (2005) developed a palm-based continuous personal travel companion focusing on pedestrian orientation and guidance in complex public transport interchange buildings. With adequate walkway network, these on-trip planning approach can provide viable guidance. However, data collection and processing for building Walkway network is difficult and time consuming.

Pedestrian navigation is hardly practical and reasonable without essential Walkway network. So building a Walkway network based on existing road network and pedestrian facilities data undoubtedly takes an important role in multi-criteria route planning.

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2. METHODOLOGY

2.1 Building the Walkway network

Some characteristics have to be considered in building walkway network:

1. Walking directions. Pedestrian walkway, unlike driving mode, has no specified directions. Thus, an undirected graph should be utilized to model the network.
2. Passing limitations. Highways and trunk roads have special traffic barrier and can only be crossed through public walking facilities such as pedestrian overpass, underpass, and pedestrian crosswalk.
3. Traffic influence immune. Traffic jam, traffic regulation or traffic accidence has little influence on walking speed. Thus, some road attributes used for real-time route searching are unnecessary for walkway network.

The walkway network is built with road network and pedestrian facilities data, which usually represented as point features. A point to line features transformation has to be conducted to provide workable routes. The goal of map generalization is to give emphasis to salient objects and their properties whilst omitting less important qualities with respect to the scale and the purpose of a map. Thus, at a coarse scale, each individual building, streetlight and pavement might be subsumed by a single point. A reverse process has to be executed in order to represent crossing road pedestrian facilities.

Based on the characteristics mentioned above and the existing road network with necessary pedestrian facilities, an automatic approach for walkway network building is proposed as Figure 1 shows.

Step 1: Selecting roadways with sidewalks in road network dataset.
Eliminating roadways without sidewalks in road dataset $R$ classified as cloverleaf, ring road, highway and its entrance or exits. The remained roadway constructs the main skeleton of walkway road, marked as $R'$.

Step 2: Establishing mapping relationship between pedestrian facilities and roadways.
For each pedestrian facilities $i$, searching roadway in $R'$ with mapping relations. The mapping relations (one to many) of pedestrian facilities $i$ is represented as a set $M(i) = \{r_1, r_2, ..., r_m | r_1, ..., r_m \in R'\}$.

For each element in $M(i)$, add roadway with pair relations and not in the current set into $M'(i)$, marked as $M'(i)$. Neighbour analysis is used to reduce the matching set $M'(i)$ and attain appropriate pre-extension pair roadways $M''(i)$.

Step 3: Generalizing a new roadway dataset for walking.
For each pedestrian facilities $i$, draw perpendicular line to matching pairs in $M''(i)$. The shortest one with pedals on the matching pairs generates new arcs and these pedals create new nodes in $N_e$ simultaneously. This process is called “dimension extending”. The related attributes are attached to the generated network.

For every newly generated node in $N_e$, it breaks the original roadway into two parts with new attributes recalculated in order to guarantee the integrity of topology on pedestrian network. These two groups of newly generated line features with those in $R'$ constitute the whole data needed for pedestrian network.

Step 4: Building topology for the pedestrian walkway network.
Build the topology for the walkway network. Note that the network topology is an undirected graph.

Figure 2 shows an example of the above process. Figure 2(a) illustrates the common situation that pedestrian facilities and roadways are located. Figure 2(b) demonstrates the pairing relations between roadways. With generated crossing nodes $N_c$ on roadway $a$ and $N_e$ on $d$, a generated line feature represents a cross street walkway, as shown in Figure 2 (c).

2.2 Multi-modal Route Planning with Walking Guidance

The following steps are designed to deal with the multi-modal route planning with the consideration of accurate walking guidance. The high priority mode expansion strategy combined
with multi-criteria evaluation provides more practical and feasible route searching result. This strategy is judging by priority of weights of every mode. Each mode is attached with different weights according to different criteria.

a) Take origin spot \( O \) as a searching centre, find every possible boarding spot \( S^m \) at mode \( m \), within a certain distance scope, and store the result in a set \( O^m = \{S^m, ..., S^m_n\} \).

b) Apply the same process to destination \( D \) and get a set \( D^m = \{S^m_1, ..., S^m_n\} \).

c) If \( O^m = \emptyset \) and \( D^m = \emptyset \) go to d), otherwise go to f).

d) Find appropriate route \( U^m(i, j) \) in mode \( m \) with start spot \( S^m_i \in O^m \) and end spot \( S^m_j \in D^m \) separately.

e) For each route \( R^m_i \in U^m(i, j) \), the boarding spot \( S^m_0 \) and alighting spot \( S^m_j \) depart the route into several parts. Take \( O-S^m_0, S^m_i - S^m_j, \) and \( S^m_j - D \) as \( O-D \) pairs, and plan appropriate route in the next priority mode. Then, turn to g).

f) Take \( O-D \) as \( O-D \) pair and plan appropriate route in the next priority mode.

g) Repeat this process a) to g) until the route is fixed.

![Figure 3 Example of route planning](image)

Figure 3 illustrates the multi-modal route result. The walkway connection strategy is applied to deal with intermediate transfers needed.

### 2.3 Route Planning Algorithm

Route-planning problem is well studied as the shortest path (SP) problem. It is formulated as a weighted, directed graph model \( G = (V, E) \), in which \( V \) represents a set of nodes and \( E \) a set of directed edges (roadways). Each edge is assigned a weight \( w(e) \). In multi-modal route planning, \( w(e) \) has to be redefined in order to reflect the difference between the travel modes involved according to various criteria. A suitable algorithm for multi-modal SP problem is modified from the classic Dijkstra’s algorithms.

Turning impedance is defined as the mount of cost or resistance, expected to pass through a road intersection from current edge to another edge aside the intersection. Higher impedance denotes greater resistance to movement. For dealing with turning impedance calculation, dual graph is used to map a traditional node graph to a line graph. Dual graph allows cost functions for traversing a segment and a vertex in node graph to be attached as attributes to graph elements in a line graph, which is useful for finding minimize cost routes between connected edges, such as waiting time at traffic lights or intersections, turn cost, or cost associated with choice options at transfers (Hochmair 2008). Dynamic inter-modal switching delay is considered as a kind of turning impedance calculated in our modified algorithm. It appears in bus, subway and taxi waiting mostly.

There are large varieties of route selection criteria considered in route choice (Golledge 1995, Hochmair 2005, Hochmair et al. 2004, Hochmair et al. 2005). For each travel mode the evaluation criteria differ, but the most common criteria are the shortest fastest, cheapest, least transfer or combination of them. The road attributes for multi-criteria evaluation are calculated as part of the roadway cost. For different criteria, different weights of these modes assigned as scales ranging from 1 to 4, where 4 represents the best case and 1 the worst. In minimal time criterion, for example, walking mode takes 1 then bus and taxi for 2 and 3, and subway mode gets 4.

Real-time traffic flow, traffic accident, temporal traffic regulation must be considered in real-time route planning. For pre-trip route computation in dynamic environment, traffic data comprise two aspects: 1) real-time traffic information when a trip is going to start; 2) Possible traffic information during a trip. The latter part pertains to historical traffic reasoning and real-time traffic forecasting.

With absorbing dynamic traffic information into route planning algorithm, this paper proposes a solution of changing traditional static route choice into more practical one. The time-related algorithm considers time cost in every node searching process. For current node, all unvisited neighbour nodes are considered and their time cost is calculated. The time cost of a route is calculated according different modes denoted as \( Cost^r, Cost^b, Cost^s \) and \( Cost^t \) for walk, bus, subway and taxi mode respectively, as shown in formula (1).

\[
Cost = Cost^r + Cost^b + Cost^s + Cost^t \tag{1}
\]

For walk mode, the cost is represented as \( Cost^r(L_w, V_w, I^r) \) in formula (2), where \( L_w \) represents length of connected roadway (edge); the velocity of pedestrian \( V_w \) is little influenced by traffic condition, and assigned as 5 km/h; turning impedance \( I^r \) is in connection with turning type.

\[
Cost^r = \frac{L_w}{V_w} + I^r \tag{2}
\]

Formula (3) illustrates bus mode, \( V^b \) is the average velocity of bus running, which is influenced by real-time traffic situation; \( T_{interval} \) denotes the interval time of bus dispatching; turning impedance \( I^b \) is determined by turning type and real-time traffic; \( T_{wa} \) represents the time cost at bus stops.

\[
Cost^b = \frac{L_w}{V^b} + \frac{1}{2} T_{interval} + I^b + T_{wa} \tag{3}
\]

For subway mode cost is calculated as formula (4) shows, in which \( V^s \) means the average velocity of subway running; \( T_{trans} \) denotes the time cost of subway transfer.

\[
Cost^s = \frac{L_w}{V^s} + \frac{1}{2} T_{interval} + T_{trans} \tag{4}
\]

\( I^b \) in formula (5) is obtained by dynamic information processing system; \( I^f \) is determined by turning type and real-time traffic, as \( I^f \) in bus mode.
The driving speed across a roadway varies with roadway type and real-time traffic. A collaborative working platform, as shown in Figure 4, is built to forecast the possible time cost across the roadways real-timely.

\[ \text{Cost} = \frac{L}{V} + t' \]

Figure 5 illustrates the priority mode-expansion strategy as well as user-free mode combination. Without specified mode, the fastest route is fixed as shown in Figure 5(a), which involves subway, taxi and walking mode. For the same O-D pair, Figure 5(b) shows the fewest transfer route.

The time-related dynamic route planning results are shown in Figure 6. Given the same O-D pair, three different routes are obtained at different time. The starting time is 07:20, 17:20 and 22:20 in (a), (b) and (c). With pre-trip route planning the on trip time are 1 hour 57 minutes, 1 hour 43 minutes and 1 hour 20 minutes. The different routes illustrate real-time traffic change.

An experiment is conducted in the study area to verify the proposed route planning approach. O-D pairs are selected randomly in four sampling areas systematically set all over the road networks. The experiment is conducted to find the fastest and the fewest transfer route under both static and dynamic environment respectively. The result is shown in Table 1.

<table>
<thead>
<tr>
<th>O-D Pairs</th>
<th>8912</th>
<th>9609</th>
<th>10409</th>
<th>10456</th>
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<tr>
<td>Mean (ms)</td>
<td>14.21</td>
<td>17.76</td>
<td>35.10</td>
<td>33.82</td>
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<tr>
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<td>68.20</td>
<td>87.04</td>
<td>129.4</td>
<td>144.8</td>
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<tr>
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<td>2.86</td>
<td>5.65</td>
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<td>St. deviation (ms)</td>
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<td>19.01</td>
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</table>

4. CONCLUSION

Diary public travel involves different transportation modes and route evaluation criteria. Walking is inevitably concerned to connect the different modes, and also an important factor for the accurate route guidance and cost calculation. Unfortunately current map websites or navigation systems have hardly considered the importance of accurate walkway network and always provide inaccurate or unclear route guidance results. Based on the road network data and the walking concerned facilities, this research embarks on traveller’s individual needs and presents an automatic approach for walkway network building, which is critical for the walking guidance during mode transfer, and also the fundamental difference with traditional approaches.

The bus, subway, taxi and walking mode are combined to construct a multi-modal transportation network, and provide transparent route planning with the user specified criteria. In this study, three criteria, namely, least transfer times, least time
duration and least fare criterion, have been identified. The historical and real-time traffic information are used for short-term traffic forecasting. With the walkway network built with the presented approach, the route searching gets more accurate and practical results. It is argued that accurate walking guidance will shortly replace the unclear mode transfer direction in current applications, and makes the route planning more reliable.

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