Two New Pedestrian Navigation Path Options based on Semi-indoor Space

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- Illustration of the Two Path Options
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INTRODUCTION

Vehicle navigation

Pedestrian navigation
Environments (spaces) where navigation happens

- Indoor
- Semi-indoor
- Outdoor
- Semi-outdoor

Semi-indoor (sl-space)

The sl-spaces are the hollow parts formed by living environments that are semi-open to the outdoors, physically enclosed by upper boundaries (e.g., roof, shelter), and may have a surrounding boundaries (e.g., wall, fence), but is not physically enclosed completely like indoor.

Examples of semi-indoor environments (spaces) formed by built structures

THE TWO PATH OPTIONS

Two new navigation path options based on semi-indoor spaces:

(i) the **Most-Top-Covered path** (**MTC-path**)

(ii) path to the **Nearest sl-space from departure** (**NSI-path**)

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*Escape from rains*  
*Escape from sun*
Duality used for navigation network derivation

Poincaré duality

The duality used in this paper
Parameters for Navigation Model

- The distance between two connected spaces ($D_{S_{ij}}$)
- Original weights ($W'_{S_{ij}}$)
- Covered ($D_{cs_{ij}}$), & uncovered ($D_{ucS_{ij}}$) distance
- Uncovered ratio ($\lambda_{S_{ij}}$)
- Modified weights ($W''_{S_{ij}}$)

Illustration of connected spaces

\[ W'_{S_{ij}} = \frac{D_{S_{ij}} - D_{S_{ij}}(\text{min})}{D_{S_{ij}}(\text{max}) - D_{S_{ij}}(\text{min})} \]

\[ \lambda_{S_{ij}} = \frac{D_{ucS_{ij}}}{D_{S_{ij}}} \]

\[ W''_{S_{ij}} = \xi W'_{S_{ij}} + (1 - \xi)\lambda_{S_{ij}} \]

$\xi$ (coefficient)
Parameters for Navigation Path

- Path length ($P_l$)
  $$P_l = \sum D_{Si}$$

- Covered/Uncovered length of a path ($P_{lc}$ / $P_{luc}$)
  $$P_{lc} = \sum D_{cSi} \quad P_{luc} = \sum D_{ucSi}$$

- Top-coverage-ratio of a path ($P_{cr}$)
  $$P_{cr} = \frac{P_{lc}}{P_l}$$

- Weight-based path length ($W_p$)
  $$W_p = \sum W_{Si}$$
Steps of path computation

MTC-path (Most-Top-Covered path)

- Select semi-indoor spaces.
- Compute the original and modified weights.
- Compute the MTC-path.

NSI-path (path to the Nearest Semi-Indoor space from departure)

- Select semi-indoor spaces.
- Create a straight line by linking the departure and destination.
- Set time (t) and searching angle (α).
- Find potential nearest sl-spaces.
- Determine the nearest sl-space and NSI-path.

Example of NSI-path planning from departure to destination.
A Path Selection Strategy

- MTC-path
- NSI-path
- The traditional shortest path

**Condition 1:** Uncovered length of a MTC-path ($P_{uc1}$) is shorter than that of the Shortest path ($P_{uc0}$)

**Condition 2:** Top-coverage-ratio of a MTC-path ($P_{cr1}$) is larger than that of the Shortest path ($P_{cr0}$)

**Condition 3:** Path length of NSI-path ($P_{l2}$) is shorter than that of the Shortest path ($P_{l0}$)

The path selection strategy
A navigation example, in which C, F and G are three sl-spaces.

(a) All spaces.
(b) Nodes extracted from spaces;
(c) Navigation graph derived from spaces based on duality theory;
(d) Navigation graph with distance.
\[ D_{SAF} = 5 + 2 = 7 \]

\[ D_{S_{ij}} = \{ D_{SA}, D_{SB}, D_{SC}, D_{SD}, D_{SE}, D_{SF}, D_{SG}, D_{SH} \} = \{ 7, 5, 8, 3, 5, 4, 7, 5, 8 \} \]

\[ D_{S_{ij}}(\text{min}) = 3 \]

\[ D_{S_{ij}}(\text{max}) = 8 \]

Original weight

\[ W'_{SAF} = \frac{D_{SAF} - D_{S_{ij}}(\text{min})}{D_{S_{ij}}(\text{max}) - D_{S_{ij}}(\text{min})} = \frac{7 - 3}{8 - 3} = 0.8 \]

Covered distance

\[ D_{cSAF} = 2 \]

Uncovered distance

\[ D_{ucSAF} = 5 \]

Uncovered ratio

\[ \lambda_{SAF} = \frac{5}{7} = 0.71 \]
Planned paths

The three navigation paths from SA (departure) to SH (destination). $SA \rightarrow SD \rightarrow SE \rightarrow SH$ is path 1 (green), $SA \rightarrow SF \rightarrow SG \rightarrow SH$ is path 2 (black), and $SA \rightarrow SF$ is path 3 (blue).
\[ \xi = 0.6 \]

Path length
\[ P_l = S_{AF} + S_{FG} + S_{GH} = 7 + 5 + 8 = 20 \]

Uncovered length of a path
\[ P_{luc} = 10 \]

Covered length of a path
\[ P_{lc} = 10 \]

Top-coverage-ratio of a path
\[ P_{cr} = P_{lc} / P_l = 10 / 20 = 0.5 \]

Weight-based path length
\[ W_p = W''_{SAF} + W''_{SFG} + W''_{SGH} = 0.77 + 0.24 + 0.85 = 1.86 \]
Path selection

The changes of $W_p$ with the changing of the coefficient $\xi$.

It reveals that with paying more attention to the top-coverage-ratio of the path, the traditional shortest path becomes less attractive.
IMPLEMENTATION

Selected area of university campus for testing.

Space & Navigation Network

Space reconstruction

<table>
<thead>
<tr>
<th>Type</th>
<th>Buildings</th>
<th>Space Types</th>
<th>Green Areas</th>
<th>Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>sI-space</td>
<td></td>
<td>sO-space</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor</td>
<td></td>
<td>O-space</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BIM spaces and 3D spaces in the test area.

Navigation network derivation based on duality

The navigation network automatically derived from 3D spaces based on duality.

Navigation Path A to B

OpenStreetMap

Path length: 4min / 292 m

Google Maps

Path length: 4min / 350 m

Our approach

Shortest path

Path length: 281.55 m
Covered distance: 10.67 m
Uncovered distance: 270.88 m
Top-coverage-ratio: 0.038

MTC-path

Path length: 291.06 m
Covered distance: 40.27 m
Uncovered distance: 250.80 m
Top-coverage-ratio: 0.138
Navigation Path C to D

OpenStreetMap

Path length 5min / 352 m

Google Maps

Path length 4min / 400 m

Our Approach

Shortest path

Path length 347.91 m
Covered distance 0
Uncovered distance 347.91 m
Top-coverage-ratio 0

MTC-path

Path length 349.59 m
Covered distance 79.11 m
Uncovered distance 270.48 m
Top-coverage-ratio 0.226
## Results

<table>
<thead>
<tr>
<th>Shortest path</th>
<th>MTC-path</th>
<th>Recommended path</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A → B</strong></td>
<td></td>
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<tr>
<td>Path length</td>
<td>281.55 m</td>
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</tr>
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### Table 4. Comparisons of three navigation systems.

<table>
<thead>
<tr>
<th>Approach</th>
<th>sI-space</th>
<th>2D/3D</th>
<th>Shortest path</th>
<th>MTC-path</th>
<th>NSI-path</th>
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</thead>
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<tr>
<td>Google Maps</td>
<td>×</td>
<td>2D</td>
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<tr>
<td>Our approach</td>
<td>✓</td>
<td>3D</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
CONCLUSION

This research has two contributions to navigation path planning:

- sl-spaces are included in navigation paths as destination or departure;

- MTC-path and NSI-path are computed for users who need the shortest path with as many covers from the top as possible;

FUTURE WORK

- Extend this research to new path options with sl-spaces to l-spaces, even sO-spaces or O-spaces;

- Investigate more aspects that are related to sl-spaces;

- Investigate the preferences of users.
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