Shortest Path Search with Constraints on Surface Models of In-ear Hearing Aids

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Overview

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2. Path search algorithm
   - Basic algorithm
   - Volume Measure extension
   - Curvature Measure extension
3. Results
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1 Motivation

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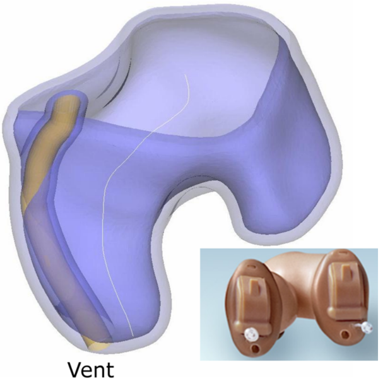
Hearing loss and hearing aids

- Approximately 8 percent of the world population suffer from hearing loss ($\approx$ 560 million people)
- Hearing aids can help these people to improve their life quality
- Hearing aids can be categorized into in-the-ear (ITE) and behind-the-ear (BTE) devices
- ITE devices have the advantage to be almost invisible to others
- Disadvantage of ITE devices is that they close the ear and so need a ventilation tube for pressure equalization

Ventilation tube to improve wearing comfort

- Ventilation tube (vent) allows pressure equalization
- Reduces feedback to the users body functions
- Vent is placed during virtual editing of a scanned ear impression
- Constraints:
  - Short
  - Optimal space usage
  - no sharp bends
  - Fast ($<$ 2sec)



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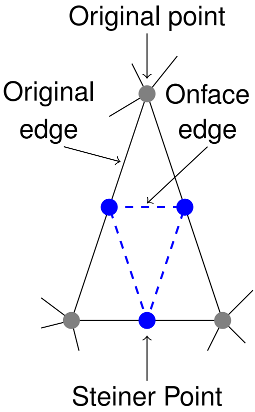
Extended Dijkstra's algorithm as basic algorithm

- Shortest path search is a standard problem in computational geometry → large number of algorithms
- Due to the time requirement approximate algorithms are preferred
- Dijkstra's algorithm was chosen, because:
  - Fast $O(n \ln n)$
  - Can handle non-convex data
  - Object function can be modified easily
- Disadvantage of Dijkstra's algorithm: quality or path length depends on the mesh granularity
- Solution: Selective Refinement of Kanai & Suzuki[1]

[1] T. Kanai and H. Suzuki. Approximate shortest path on a polyhedral surface and its applications. *In GMP '00: Proceedings of the Geometric Modeling and Processing 2000*, page 241 – 250, 2000. IEEE Computer Society.

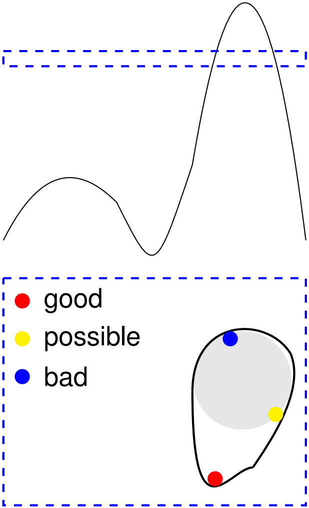
Selective Refinement

- Refinement:
  - Introduces so-called Steiner Points into the mesh
  - Allows the path to go across mesh triangle
- Selective:
  - Iterative selection of the mesh content
  - First run complete mesh is used
  - Following runs only the path and its neighbors are used
  - Allows fast computation despite the introduction of new points and edges



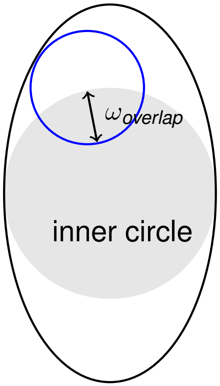
Volume Measure extension

- Motivation: Space inside an ITE is small and valuable
- Electric components like receiver and battery needs space
- Vent shall use space which is not or less valuable



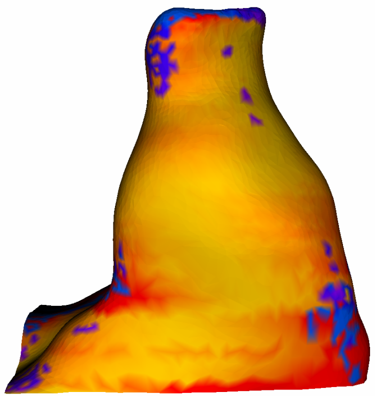
Formulation of the Volume Measure

- Dijsktra's algorithm depends only on the Euclidean edge length ω_E
- VM is used as an additional weight ω_{VM}
- VM is composed out of two parts:
  - Possibility to place a vent – ω_{poss}
  - Overlapping distance of inner circle and vent – $\omega_{overlap}$
  - $\omega_{VM} = \omega_{poss} + \omega_{overlap}$



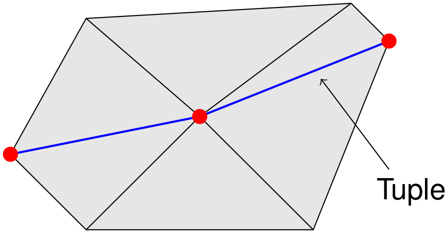
Formulation of the Volume Measure

- Combine Euclidean length and Volume Measure into a new object function f
- $f_{i,j} = \omega_{E,i,j} + \beta \cdot \omega_{VM,j}$
- $\beta \in \mathbb{R}^{+}$, control variable



Curvature Measure

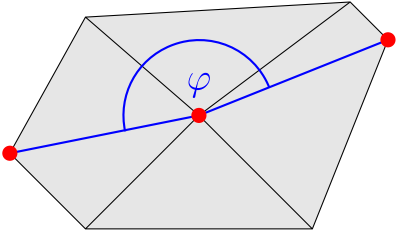
- Motivation: Sharp bends worses the functionality of the vent
- Penalize sharp bends / kinks on the path
- Extending of the algorithm to work on tuples
- Every tuple has as an additional weight – its enclosed angle φ



Disadvantage:
1 vertex with n neighbors
results in $n(n-1)/2$ tuples

Formulation of the Curvature Measure

- CM is similarly to VM used as an additional weight in the object function f
- $\omega_{CM,j} = |180 - \varphi_j|$



- $f_{i,j} = \omega_{E,i,j} + \beta \cdot \omega_{VM,j} + \delta \cdot \omega_{CM,j}$
- $\delta \in \mathbb{R}^+$, control variable

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Experimental results

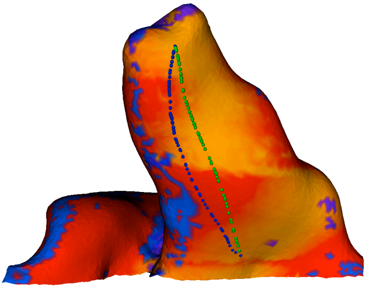
Algorithm combination	Path length	VM costs c_{VM}	VM costs c_{CM}	Runtime
DA, SR	0.83	36.5	5.7	0.4sec
DA, SR, VM	0.84	22.6	8.2	1.4sec
DA, SR, CM	0.93	46.5	4.0	86.1sec
DA, SR, VM, CM	0.92	37.5	3.9	86.5sec

Table: Mesh size 6000 vertices, $\beta = 5$ and $\delta = 0.005$.

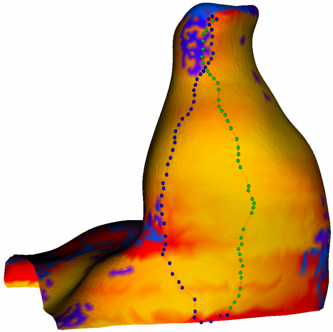
$$c_{VM} = \sum_{i=0}^{P} \omega_{VM,i} \qquad c_{CM} = \sum_{i=0}^{P} \omega_{E,i} \cdot \omega_{CM,i}$$

Results were evaluated by experts as superior in comparison with the standard shortest path algorithm.

Experimental results



Comparison of DA, SR (green) and DA, SR, VM (blue)



Comparison of DA, SR, VM, CM (green) and DA, SR, CM (blue)

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- New shortest path algorithm, which is well adapted for the requirements of the vent placement
- Basis: Dijkstra's algorithm and Selective Refinement
- Volume Measure: optimizes space usage
- Curvature Measure: prevents sharp bends
- Evaluated by experts: superior to simple shortest path solution