Automatic reconstruction of urban wastewater and stormwater networks based on uncertain manhole cover locations

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Lack of information about buried utility networks in both developed and developing countries => delays, increased costs, sub-optimal management of resources.
Can an existing network be mapped based on manhole cover locations?

Optimal configuration may be determined (Walter, 1995; Afshar, 2007; Swamee & Sharma, 2013; Moeini and Afshar, 2012)

Existing network layout may be reproduced if node to link or PE data is available (Allard et al., 2013; Blumensaat et al., 2012)
The methodology (1/2)

- Assumption: Manhole covers are a set $S$ of georeferenced points $P_i(x_i, y_i)$ and the nodes of the network to be reconstructed. They can be detected using high resolution imagery (Pasquet et al., 2016; Commandré et al., 2017).

- Step 1: Compute a Delaunay triangulation based on the set $S$.
  - Assign $c(P_iP_j)$ i.e the “cost” for wastewater to flow from $P_i$ to $P_j$. $c(P_iP_j) = -c(P_jP_i)$

- Step 2: Extract the Minimum Spanning Tree using Kruskal’s algorithm (1956).
The methodology (2/2)

- Two examples of cost functions
  
  ! Assume surface and underground slopes to be parallel  !

- \( c_1(P_iP_j) = \left( \alpha \frac{l_{ij}}{l_{\text{max}}} - (1 - \alpha) \frac{\Delta z_{ij}}{\Delta z_{\text{max}}} \right) + \beta + \gamma \)

  - \( l_{ij} \): length of edge \( P_iP_j \)
  - \( \Delta z_{ij} \): elevation difference between nodes \( P_i \) and \( P_j \)
  - \( \alpha \): a weight to balance the influence of the length and the elevation
  - \( \beta, \gamma \): penalty parameters when the edge intersects a road or a building

- \( c_2(P_iP_j) = \alpha \frac{\text{rank}(l_{ij})}{\text{max}(\text{rank}(l_{ij}))} + (1 - \alpha) \delta \frac{\text{rank}(|S_{ij} - S_m|)}{\text{max}(\text{rank}(S_{ij} - S_m))} + \beta + \gamma S_{ij} \)

  - \( S_{ij} \): slope of edge \( P_iP_j \)
  - \( S_m \): mean value of the interval [2 %, 7 %]
  - \( \delta = 0 \) if the slope is in the interval, otherwise \( \delta = 1 \)
Case study: Prades-Le-Lez (Southern France)

- 799 manhole covers and 23.45km of pipes (operator data).
- Geographical data base (DEM, roads, buildings) available through IGN.

- Randomly select ½ of manhole covers to test the algorithm
- Assess and compare
  - Correctness, completeness, quality (Heipke et al., 1997).
  - Network hierarchy (Shreve, 1966).
  - Distance to the outlet (Allard et al. 2013).
Results (1/3) : cost function 1

<table>
<thead>
<tr>
<th>Cost function</th>
<th>Correctness</th>
<th>Completeness</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>All nodes</td>
<td>0.89</td>
<td>0.84</td>
<td>0.76</td>
</tr>
<tr>
<td>Half of the nodes</td>
<td>0.44</td>
<td>0.55</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Small segments tend to disappear : Shreve magnitude drops from 131 to 84
Mainforce in the western part of the catchment cannot be accounted for
## Results (2/3) : cost function 2

<table>
<thead>
<tr>
<th>Cost function</th>
<th>Correctness</th>
<th>Completeness</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>All nodes</td>
<td>0.90</td>
<td>0.93</td>
<td>0.84</td>
</tr>
<tr>
<td>Half of the nodes</td>
<td>0.54</td>
<td>0.66</td>
<td>0.42</td>
</tr>
</tbody>
</table>

All three criteria have higher values than with cost function 1

Shreve magnitude is 96
The second cost function yields more realistic results.
Conclusion and perspectives

- Manhole cover location can be used to create wastewater network maps.
  - When using VHR images false positives may be included
  - Stormwater manhole covers may be confused with wastewater ones
  - Slope is the least reported variable... and the most sensitive in hydraulic modelling...

- Perspectives
  - Determination of the geometric features of the network? Can data mining be helpful?
  - What about uncertainty? Include noise and generate probable network configurations.
  - Does it work elsewhere? Insure genericity by testing on more catchments.
Mapping examples found in the literature for stormwater/wastewater networks

- Optimise network layout using
  - Dynamic programming (Walter, 1995)
  - Linear programming (Swamee and Sharma, 2013)
  - Ant algorithms (Afshar, 2007; Moeini and Afshar, 2012)

- Reproduce the layout of existing networks using node to link information provided by urban databases and operators (Allard et al., 2013 and Blumensaat et al., 2012)