Texture-Based Region Tracking Using Gaussian Markov Random Fields for Cilia Motion Analysis

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Introduction

- **Motile Cilia**
  - Protect the respiratory system.
  - Protection function is performed by ciliary beating.
  - Defect on this function leads to the impairment of Mucociliary clearance.
  - Primary ciliary dyskinesia (PCD) is associated with ciliary beating abnormality.

- **Ciliary beating motion (CBM)**
  - Tracking (CBM) to understand its behaviour.
  - Beneficial for diagnosis.
Introduction

- **Challenges**
  - Low contrast.
  - Moving textured regions.
  - Textures regions are moving with textured background.
  - Camera calibration.

- **Proposed solution**
  - Ciliary beating appears as a moving texture.
  - Region tracking based on texture feature.
  - Extract CBM trajectory.
Method

- Method overview

**Video**
- **Optical flow** is used to extract regions of interest i.e. beating cilia area

**Preprocessing**
- **Texture feature** is extracted using GMRF

**Feature extraction**
- **Region tracking** is performed using block-matching search technique based on GMRF features

**Region tracking**
- **trajectory vector** of the tracked region is extracted depicting the pattern of *cilia motion* over all frames

**Motion Trajectory extraction**

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Preprocessing

- **Optical flow**
  - Region of interest i.e. beating cilia regions
    - The optical flow is estimated using Horn-Schunck method.
    - The magnitude components are accumulated.
    - The accumulated magnitude at specific threshold is considered to extract beating cilia regions
  - Advantage: Less computation time is required
Feature extraction

- Gaussian Markov Random Fields model.

\[
p(g_s | y_{s+r}, r \in N) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left\{ -\frac{1}{2\sigma^2} \left( g_s - \lambda - \sum_{r \in N} \alpha_r (y_{s+r} - \lambda) \right)^2 \right\}
\]

- \( g_s \): Value of central pixel.
- \( y_r \): Intensity values of neighbours.
- \( \lambda \): Mean of the processed region.
- \( \alpha_s \): Interaction parameters (coefficient).
- \( \sigma^2 \): Variance.

Parameters to be estimated:

1. \( \alpha_s = [\alpha_1, \alpha_2, \ldots, \alpha_r] \)
2. \( \sigma_s^2 \)

Neighbourhood scheme
Feature extraction

- Local estimation of parameters $\alpha_s$, $\sigma_s^2$
- Maximum likelihood estimation (MLE)

Solution:

$$\alpha_s = \left( \sum_{s \in \Omega_s} y_s y_s^T + cI \right)^{-1} \left( \sum_{s \in \Omega_s} y_s g_s \right)$$

$$\sigma_s^2 = \frac{1}{|\Omega_s|} \sum_{s \in \Omega_s} (g_s - \alpha_s y_s)^2$$

$C$ : Regularisation parameter.
$l$ : Identity matrix
Feature extraction

\[
\begin{array}{ccc}
  y_1 & y_2 & y_3 \\
  y_5 & g_x & y_4 \\
  y_7 & y_6 & y_5 \\
\end{array}
\]

GMRF Parameter estimation

\[
\begin{array}{cccccc}
  \alpha_1 & \alpha_2 & \ldots & \alpha_r & \sigma^2_s & \lambda_s \\
\end{array}
\]

Feature vector for each pixel
Region tracking

\[ d_k = \sqrt{\sum_i (f_{qk}(i) - f_p(i))^2} \]

\[ D(1,1) = \sum_k d_k \]

\[ D(X,Y) = \min(D) \]
Evaluation

- Synthetic samples
  - Size 64x64, 64 frames

<table>
<thead>
<tr>
<th>Neighborhood</th>
<th>w = 3</th>
<th>w = 5</th>
<th>w = 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>2.53±1.54</td>
<td>8.20±3.37</td>
<td>19.71±7.70</td>
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</tbody>
</table>
Evaluation

- Medical sample of cilia video *Size 512x512, 512 frames*

<table>
<thead>
<tr>
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<th>w = 5</th>
<th>w = 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>21.48±8.45</td>
<td>2.80± 5.59</td>
<td>4.72 ± 4.0</td>
</tr>
</tbody>
</table>
Performance

![Bar chart showing performance comparison between GMRF and Region tracking for different region sizes (m×m). The x-axis represents the region size, and the y-axis represents the time (second). The chart includes data for region sizes of 5, 7, 9, 11, 13, 15, 17, and 19 (m×m).]
Conclusions

- A new method for region tracking based on texture feature is proposed for cilia motion tracking.
- Experiments outcome demonstrates the capability of texture feature to track a textured region under different challenges.
Thank You!