Decreasing the Measurement Time of Blood Sugar Tests using Particle Filtering
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Motivation and Application

- Frequent self-monitoring of blood sugar levels is essential for diabetics
- Using a novel photometric measurement setup for hand-held devices requires a much smaller blood sample volume.
- The usability of hand-held glucometers is crucially affected by the measurement time

Image-based Photometric Measurement Setup

How do we measure the glucose concentration of a blood sample in hand-held devices?

- The region of interest (ROI) is the blood-filled area of the test strip
- We measure the amount of light reflected from the ROI: the relative remission \( R_{\text{sat}} \)
- \( R_{\text{sat}} \) can directly be mapped to the underlying glucose concentration \( C \) in the blood

Goals

- Decrease the measurement time of blood sugar tests using hand-held glucometers
- Become independent of computationally costly statistical clustering methods for segmentation of the ROI and the remainder of the test-strip

Challenges

- Obtain a reliable estimate of the required relative remission value \( R_{\text{sat}} \) at an early stage of the chemical reaction

Modeling and State-Space Approach

- The temporal behavior of the chemical reaction for \( t \geq t_0 \) can be modeled as:

\[
R(t) = (R_{\text{drop}} - R_{\text{sat}}) \cdot e^{(-t/t_d)} + R_{\text{sat}}
\]

How can we use this model to decrease the measurement time?

- True final remission value \( R_{\text{sat}} \) is the hidden state of the system
- Pixels of the pre-processed image are the available observations
- System model:

\[
R_{\text{sat}} = R_{\text{sat},t-1} + u_{t-1} \quad \text{with } u_t \sim N(0, \sigma_u^2) \quad \forall t \in \mathbb{R}
\]

- Observation model (pixels):

\[
I_t(m,n) = (R_{\text{drop}} - R_{\text{sat}}) \cdot e^{(-t/t_d)} + R_{\text{sat}} \quad \forall (m,n) \in M \times N
\]

Particle Filtering

- Recursive Bayesian filtering approach to estimate the state from incoming observations
- Particle filter: approximate the filtering distribution by \( N_p \) samples, so-called particles, as

\[
p(R_{\text{sat}}|I_{1:t}) \propto \sum_{i=1}^{N_p} w_t^i \delta(R_{\text{sat}} - R_{\text{sat}}^{i,t})
\]

- Update weights \( w_t^i \) by evaluating the likelihood

\[
p(I_t|R_{\text{sat}}^{i,t}) = \frac{f(I_t|R_{\text{sat}}^{i,t})}{f(I_t)}
\]

- Likelihood: kernel density estimate \( f \) of the PDF of propagated pixel intensities \( f_{\text{prop}} = \frac{1}{V_{\text{ROI}}} \sum_{j=1}^{V_{\text{ROI}}} f_j \)

- At each time instant \( t \) : obtain an estimate of the state of the system by

\[
R_{\text{EST}}^{\text{NEW}} = R_{\text{EST}}^{\text{OLD}} + \frac{1}{N_p} \sum_{i=1}^{N_p} w_t^i R_{\text{sat}}^{i,t}
\]

Results using Real Measurements

Measurement Setup & Simulation Parameters

- 78 real measurement videos of 20 s duration captured at 30 frames per second were provided by Roche Diagnostics GmbH, Mannheim, Germany
- 16 different known underlying glucose concentrations (ranging from 30 mg/dl to 550 mg/dl) are investigated
- Decay rate \( t_d \) in the model is estimated from the test set
- 2 fixed, overlapping image regions are chosen as particle filter inputs
- Particle filter uses \( N_p = 500 \) particles per image region

Results

- Average testing time is reduced by approximately 50% - even up to 65% for single measurements
- (Clinical) accuracy and precision of results are comparable to the state-of-the-art method
- The average computational costs per frame are reduced by approximately 60%

Variation coefficient: gMAD in mg/dl:

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<th>Ref</th>
<th>New</th>
<th>Ref</th>
<th>New</th>
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</thead>
<tbody>
<tr>
<td>C ≤ 100</td>
<td>0.37</td>
<td>1.06</td>
<td>C ≤ 75</td>
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<td>Overall</td>
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<td>0.28</td>
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Conclusions

- Proposed method can drastically decrease the measurement time of blood sugar tests
- Results obtained using real measurements are comparable to the state-of-the-art method
- Computational costs can be mitigated by omitting statistical segmentation procedures