FAST ADAPTIVE FRAME PREPROCESSING FOR 3D RECONSTRUCTION

Fabio Bellavia
Marco Fanfani
Carlo Colombo

VISAPP 2015
Goal

Give an insight of bad frames in the video sequence:

- (relatively) blurred frames
- unchanged frames
Goal

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Double Window Adaptive Frame Selection (DWAFS):

- label bad frames
- adaptive gradient statistic
- fast computation
- preprocessing step (to take action on the computational flow accordingly)
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- label bad frames
- adaptive gradient statistic
- fast computation
- preprocessing step (to take action on the computational flow accordingly)
DWAFS is not:

- a keyframe selector (no 3D and image feature data used)
- a deblurring method (only an indirect relative degree of blur is evaluated)
Method overview

Two moving average windows on the frame gradient order statistic:

- previous good n frames
- last current n frames

mix them adaptively to get a threshold value
Method overview

Two moving average windows on the frame gradient order statistic:
- previous good $n$ frames
- last current $n$ frames
mix them adaptively to get a threshold value
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Two moving average windows on the frame gradient order statistic:

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Gradient order statistic

Image gradient marks:
- image blur/sharpness
- relevant image structures (borders, keypoints)
- image flatness

higher gradient percentile value for good frames
Illustrating example

\[p^m \quad \ldots \quad 8 \quad 0 \quad 9 \quad 1 \quad 6 \quad 4 \quad 4 \quad 5 \quad 3 \quad 2 \quad \ldots\]
Illustrating example

\[ p^m \]

\[ \cdots \; 8 \; 0 \; 9 \; 1 \; 6 \; 4 \; 4 \; 5 \; 3 \; 2 \; \cdots \]

(gradient m-th percentile)

t frame
Illustrating example

(index of previous good frame at time t)

<table>
<thead>
<tr>
<th>$S_t$</th>
<th>$I_{t-8}$</th>
<th>$I_{t-6}$</th>
<th>$I_{t-4}$</th>
<th>$I_{t-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$p^m$</th>
<th>8</th>
<th>0</th>
<th>9</th>
<th>1</th>
<th>6</th>
<th>4</th>
<th>4</th>
<th>5</th>
<th>3</th>
<th>2</th>
<th>...</th>
</tr>
</thead>
</table>
Illustrating example

<table>
<thead>
<tr>
<th>$S_t$</th>
<th>...</th>
<th>$I_{t-8}$</th>
<th>$I_{t-6}$</th>
<th>$I_{t-4}$</th>
<th>$I_{t-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p^m$</td>
<td>...</td>
<td>8</td>
<td>0</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

(previous n good frames)
Illustrating example

\[ S_t \quad \ldots \quad I_{t-8} \quad I_{t-6} \quad I_{t-4} \quad I_{t-1} \]

\[ p^m \quad \ldots \quad 8 \quad 0 \quad 9 \quad 1 \quad 6 \quad 4 \quad 4 \quad 5 \quad 3 \quad 2 \quad \ldots \]

(last current \( n \) frames)
Illustrating example

\[ S_t \quad \ldots \quad I_{t-8} \quad I_{t-6} \quad I_{t-4} \quad I_{t-1} \]

\[ p^m \quad \ldots \quad 8 \quad 0 \quad 9 \quad 1 \quad 6 \quad 4 \quad 4 \quad 5 \quad 3 \quad 2 \quad \ldots \]

\[ A_t \quad 3 \quad 4 \quad 4 \quad 5 \quad 5 \quad 6 \quad 8 \quad 9 \]

(merged and sorted \( B_t + C_t \))
Illustrating example

\[ S_t \quad \ldots \quad I_{t-8} \quad I_{t-6} \quad I_{t-4} \quad I_{t-1} \]

\[ p^m \quad \ldots \quad 8 \quad 0 \quad 9 \quad 1 \quad 6 \quad 4 \quad 4 \quad 5 \quad 3 \quad 2 \quad \ldots \]

\[ A_t \quad 3 \quad 4 \quad 4 \quad 5 \quad 5 \quad 6 \quad 8 \quad 9 \]

(mixed window)
Illustrating example

\[ S_t \quad \ldots \quad I_{t-8} \quad I_{t-6} \quad I_{t-4} \quad I_{t-1} \]

\[ P^m \]

\[ B_t \quad C_t \]

\[ A_t \]

\[ F_t \]

Accept the frame if

\[ p_{t+1}^m > E(F_t) - 2 \text{ std}(F_t) \]
Illustrating example

\[
\begin{array}{cccc}
S_t & \ldots & I_{t-8} & I_{t-6} & I_{t-4} & I_{t-1} \\
\hline
B_t & \ldots & 8 & 0 & 9 & 1 & 6 & 4 & 4 & 5 & 3 & 2 & \ldots \\
\hline
A_t & 3 & 4 & 4 & 5 & 5 & 6 & 8 & 9 \\
\end{array}
\]

(shift \( F_t \) rightward as the frame is good)
Illustrating example

<table>
<thead>
<tr>
<th>$S_{t+1}$</th>
<th>$I_{t-8}$</th>
<th>$I_{t-6}$</th>
<th>$I_{t-4}$</th>
<th>$I_{t-1}$</th>
<th>$I_{t}$</th>
</tr>
</thead>
</table>

| $p^m$ | 8 | 0 | 9 | 1 | 6 | 4 | 4 | 5 | 3 | 2 | ... |

frame $t+1$
Illustrating example

\[
\begin{array}{cccccccc}
S_{t+1} & \ldots & I_{t-8} & I_{t-6} & I_{t-4} & I_{t-1} & I_t \\
\hline
p^m & \ldots & 8 & 0 & 9 & 1 & 6 & 4 & 4 & 5 & 3 & 2 & \ldots \\
B_{t+1} & & & & & &
\end{array}
\]
Illustrating example

\[
\begin{array}{cccccc}
S_{t+1} & \ldots & I_{t-8} & I_{t-6} & I_{t-4} & I_{t-1} & I_t \\
p^m & \ldots & 8 & 0 & 9 & 1 & 6 & 4 & 4 & 5 & 3 & 2 & \ldots
\end{array}
\]
Illustrating example

\[
S_{t+1} \quad \ldots \quad I_{t-8} \quad I_{t-6} \quad I_{t-4} \quad I_{t-1} \quad I_t \\
\]

\[
p^m \quad \ldots \quad 8 \quad 0 \quad \boxed{9 \quad 1 \quad 6 \quad 4} \quad 4 \quad 5 \quad 3 \quad 2 \quad \ldots \\
\]

\[
A_{t+1} \quad 2 \quad 3 \quad 3 \quad 4 \quad 5 \quad 5 \quad 6 \quad 9 \\
\]
Illustrating example

\[
\begin{array}{cccccc}
S_{t+1} & \ldots & I_{t-8} & I_{t-6} & I_{t-4} & I_{t-1} & I_t \\
\hline
p^m & \ldots & 8 & 0 & 9 & 1 & 6 & 4 & 4 & 5 & 3 & 2 & \ldots \\
A_{t+1} & 2 & 3 & 3 & 4 & 5 & 5 & 6 & 9
\end{array}
\]
Illustrating example

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\begin{array}{cccccc}
S_{t+1} & \ldots & I_{t-8} & I_{t-6} & I_{t-4} & I_{t-1} & I_t \\
\hline
\end{array}
\]

\[
\begin{array}{ccccccc}
p^m & \ldots & 8 & 0 & 9 & 1 & 6 & 4 & 4 & 5 & 3 & 2 & \ldots \\
\hline
\end{array}
\]

\[
\begin{array}{ccccccc}
A_{t+1} & 2 & 3 & 3 & 4 & 5 & 5 & 6 & 9 \\
\hline
\end{array}
\]

\[
B_{t+1} \quad C_{t+1} \quad F_{t+1}
\]

don’t accept the frame since
\[p^m_{t+1} < E(F_{t+1}) - 2 \text{ std}(F_{t+1})\]
Illustrating example

\[ S_{t+1} \ldots I_{t-8} \quad I_{t-6} \quad I_{t-4} \quad I_{t-1} \quad I_t \]

\[ p^m \]

\[ p^m \quad 8 \quad 0 \quad 9 \quad 1 \quad 6 \quad 4 \quad 4 \quad 5 \quad 3 \quad 2 \quad \ldots \]

\[ A_{t+1} \]

\[ B_{t+1} \quad C_{t+1} \]

\[ F_{t+1} \]

\[ d_t \text{ (shift } F_{t+1} \text{ leftward because the frame was not good)} \]
Observations

- DWAFS assumes that the good frame distribution can be derived from the previous best frames
- if this distribution changes DWAFS adaptively switches to the current frame distribution as more bad frames are detected

```matlab
function S=dwafs(p,w)
% input:
% - p (lxn double array) gradient percentiles
% - w (integer) window size
% output:
% - S (lxn boolean array) good frame set

S=zeros(size(p));
B=[];
d=w;
for t=1:length(p);
    if t<=w
        B=[B p(t)];
    else
        C=p(t-w+1:t);
        A=sort([C,B]);
        F=A(ceil(d)+1:ceil(d)+w);
        m=mean(F);
        s=std(F);
        if p(t)>m-2*s
            S(t)=1;
            B=[B(2:end) p(t)];
            d=min(w,d+1);
        else
            d=max(0,d-0.5);
        end;
    end;
end;
```
Still another example
Still another example

threshold on the sample \( [p_{O_t}^m, p_{T_t}^m] \)
(cannot rapidly adapt to the distribution changes)
Still another example

threshold on the previous n best frames
(cannot handle rapid gradient decreases)
Still another example

$p^m$

Cₜ threshold (last n frames, too delayed)
Still another example

threshold on $B_t$ (depend upon $C_t$, $A_t$ and $F_t$)
Still another example

threshold on $A_t = B_t + C_t$
Still another example

\[ p_m \]

DWAFS (threshold on \( F_\tau \), better following the changes)
Still another example

DWAFS good frames
Still another example
Still another example

Good frames: a, d, f
Bad frames: b, c, e
Still another example

(B) is discarded although similar to (d) and (f) since it comes after a better video context.
Evaluation

Structure-from-Motion 3D reconstruction on:

- the Monk video sequence
- the Desktop0, Desktop1, Desktop2 (increasing camera shakes and blur)
Evaluation

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Structure-from-Motion 3D reconstruction on:
- the Monk video sequence
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Evaluation

Two setups:

- full sequence vs DWAFS vs DWAFS complement
- uniform decimated sequence vs closest DWAFS

(n=video fps, uniform step=n/2)
Evaluation

Valuation on:
- 3D pts
- pts per image
- reprojection error
- track length

Facts:
- track length x 3D pts ≈ frames x pts per images
- denser and accurate reconstruction needs more 3D pts with higher track length or more pts per image and lower reprojection error
Results 1

Total number of 3D pts

Avg pts per image

Avg reproj. error per 3D pt

Avg track length
Results 1

**Goal**

**Evaluation**

**Conclusion**

**Results**

**DWAFS**

DWAFS complement
full sequence

<table>
<thead>
<tr>
<th></th>
<th>Total number of 3D pts</th>
<th>Avg pts per image</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Monk</td>
<td>4600</td>
<td>700</td>
<td>0.37</td>
<td>60</td>
</tr>
<tr>
<td>Desktop</td>
<td>2850</td>
<td>700</td>
<td>0.51</td>
<td>16</td>
</tr>
<tr>
<td>Desktop</td>
<td>8700</td>
<td>1000</td>
<td>0.56</td>
<td>35</td>
</tr>
<tr>
<td>Desktop</td>
<td>9600</td>
<td>900</td>
<td>0.80</td>
<td>70</td>
</tr>
</tbody>
</table>

**Monk**

<table>
<thead>
<tr>
<th></th>
<th>3D pts</th>
<th>img. pts</th>
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<th>track len</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>700</td>
<td>700</td>
<td>0.37</td>
<td>60</td>
</tr>
<tr>
<td>85</td>
<td>700</td>
<td>700</td>
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<tr>
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<td>60</td>
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<tr>
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**Desktop**

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<tr>
<td>95</td>
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<td>700</td>
<td>0.51</td>
<td>16</td>
</tr>
<tr>
<td>98</td>
<td>2850</td>
<td>700</td>
<td>0.51</td>
<td>16</td>
</tr>
</tbody>
</table>

**Desktop1**

<table>
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<tr>
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<td>8700</td>
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<td>35</td>
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<td>35</td>
</tr>
<tr>
<td>98</td>
<td>8700</td>
<td>1000</td>
<td>0.56</td>
<td>35</td>
</tr>
</tbody>
</table>

**Desktop2**

<table>
<thead>
<tr>
<th></th>
<th>3D pts</th>
<th>img. pts</th>
<th>error (px)</th>
<th>track len</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>9600</td>
<td>900</td>
<td>0.80</td>
<td>70</td>
</tr>
<tr>
<td>85</td>
<td>9600</td>
<td>900</td>
<td>0.80</td>
<td>70</td>
</tr>
<tr>
<td>90</td>
<td>9600</td>
<td>900</td>
<td>0.80</td>
<td>70</td>
</tr>
<tr>
<td>95</td>
<td>9600</td>
<td>900</td>
<td>0.80</td>
<td>70</td>
</tr>
<tr>
<td>98</td>
<td>9600</td>
<td>900</td>
<td>0.80</td>
<td>70</td>
</tr>
</tbody>
</table>
### Results 1

(Lower reprojection error in all cases)

<table>
<thead>
<tr>
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<th>Avg track length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monk</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>Desktop0</td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
</tr>
<tr>
<td>Desktop1</td>
<td><img src="image9" alt="Graph" /></td>
<td><img src="image10" alt="Graph" /></td>
<td><img src="image11" alt="Graph" /></td>
<td><img src="image12" alt="Graph" /></td>
</tr>
<tr>
<td>Desktop2</td>
<td><img src="image13" alt="Graph" /></td>
<td><img src="image14" alt="Graph" /></td>
<td><img src="image15" alt="Graph" /></td>
<td><img src="image16" alt="Graph" /></td>
</tr>
</tbody>
</table>

Fabio Bellavia  
fabio.bellavia@unifi.it

Fast Adaptive Frame Preprocessing For 3D Reconstruction
Results 1

Monk and Desktop2 (more stable, less camera shakes)
1) more 3d/2d pts
2) lower track length as more pts included

Total number of 3D pts
Avg pts per image
Avg reproj. error per 3D pt
Avg track length

Monk
3D pts
2700
4600
Total
Deskttop0
3D pts
10100
28500
Total
Desktop1
3D pts
5500
8700
Total
Desktop2
3D pts
2200
9600
Total
Results 1

Desktop0 and Desktop1
i) less 3d pts ii) improved track length with a low 2d pts drop

Total number of 3D pts | Avg pts per image | Avg reproj. error per 3D pt | Avg track length
---|---|---|---
Monk

3D pts | img pts | error (px) | track len
---|---|---|---
700 | 80 | 85 | 90 | 95 | 98 | n.d.
2700 | 4600

Desktop0

3D pts | img pts | error (px) | track len
---|---|---|---
10100 | 28500

Desktop1

3D pts | img pts | error (px) | track len
---|---|---|---
5500 | 8700

Desktop2

3D pts | img pts | error (px) | track len
---|---|---|---
2200 | 9600

Fabio Bellavia  fabio.bellavia@unifi.it
Fast Adaptive Frame Preprocessing For 3D Reconstruction
### Results 1

**DWAFLS complement could be similar to DWAFLS if the whole sequence is almost good (as a uniform sampling)**

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<tr>
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<tr>
<td><strong>Monk</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D pts</td>
<td>4600</td>
<td>700</td>
<td>0.37</td>
<td>40</td>
</tr>
<tr>
<td>percentile m</td>
<td>80  85  90  95  98</td>
<td>n.d.</td>
<td>80  85  90  95  98</td>
<td>n.d.</td>
</tr>
<tr>
<td></td>
<td>2700</td>
<td>100</td>
<td>0.31</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td></td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>2D pts</td>
<td>2850</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>percentile m</td>
<td>80  85  90  95  98</td>
<td>n.d.</td>
<td>80  85  90  95  98</td>
<td>n.d.</td>
</tr>
<tr>
<td></td>
<td>19000</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>10100</td>
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</tr>
<tr>
<td>2D pts</td>
<td>8700</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>percentile m</td>
<td>80  85  90  95  98</td>
<td>n.d.</td>
<td>80  85  90  95  98</td>
<td>n.d.</td>
</tr>
<tr>
<td></td>
<td>7100</td>
<td></td>
<td>0.56</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>5500</td>
<td></td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>2D pts</td>
<td>9600</td>
<td></td>
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<td>80  85  90  95  98</td>
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</tr>
<tr>
<td></td>
<td>9900</td>
<td></td>
<td>0.80</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>3900</td>
<td></td>
<td>0.60</td>
<td></td>
</tr>
</tbody>
</table>

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**Fast Adaptive Frame Preprocessing For 3D Reconstruction**

Fabio Bellavia  fabio.bellavia@unifi.it
Results 2

<table>
<thead>
<tr>
<th>Total number of 3D pts</th>
<th>Avg pts per image</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Monk</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D pts</td>
<td></td>
<td></td>
<td></td>
</tr>
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Results 2

(lower error)

Total number of 3D pts

Avg pts per image

Avg reproj. error per 3D pt

Avg track length

Monk

3D pts

percentile m

img pts

percentile m

error

px

track len

Desktop0

3D pts

percentile m

img pts

percentile m

error

px

track len

Desktop1

3D pts

percentile m

img pts

percentile m

error

px

track len

Desktop2

3D pts

percentile m

img pts

percentile m

error

px

track len
Results 2

(lower error)  (almost equal track length)

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<tr>
<td>Avg track length</td>
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Fabio Bellavia  fabio.bellavia@unifi.it

Fast Adaptive Frame Preprocessing For 3D Reconstruction
Results 2

(more 2D/3D pts)  (lower error)  (almost equal track length)

Total number of 3D pts

Avg pts per image

Avg reproj. error per 3D pt

Avg track length

Monk

Desktop0

Desktop1

Desktop2
Results 2

almost best percentile: 95%

(more 2D/3D pts)

(lower error)

(almost equal track length)

Total number of 3D pts

Avg pts per image

Avg reproj. error per 3D pt

Avg track length

Monk

Desktop0

Desktop1

Desktop2
Conclusion

Pros:
- **DWAFS** is effective to detect good frames
- adaptive and sufficiently robust
- very fast preprocessing
- easy to implement

Cons:
- not a full keyframe selector (more data analysis needed)
- its decision are relative and not global
- depend upon the window size $n$
Future work

- embed DWAFS with keyframe selectors
- test on MonoSLAM systems
- easier and clear validation setup
- evaluation on more video sequences
Thanks for your attention
QUESTIONS

asks for your attention