4-16

# Fast Combined Separability Filter for Detecting Circular Objects

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**Goal**

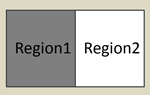
Detecting circular features in an image of the human face, with high speed and precision.

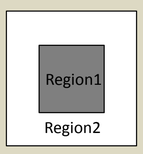
## 1: Separability Filter

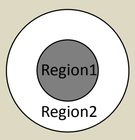
Outputs **Separability η(0.0 ≤ η ≤ 1.0)** of two regions of an image.
Robust to noise and low contrast edges.

**Separability** (Fisher Criterion)

- Ratio of total variance and between-class variance.




N1: Number of pixels in region1

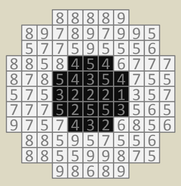
N2: Number of pixels in region2

N = N1 + N2

$\overline{P1}$ = sum( 2 3 4 2 ・・・・ )/N1

$\overline{P2}$ = sum( 5 4 8 7 ・・・・ )/N2

$\overline{P}$ =($\overline{P1}$*N1+$\overline{P2}$*N2)/N

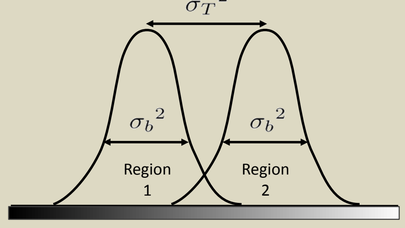


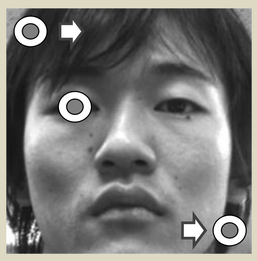
$$\eta = \frac{{\sigma_b}^2}{{\sigma_T}^2},$$

$${\sigma_b}^2 = \frac{N_1}{N}(\overline{P_1}-\overline{P})^2 + \frac{N_2}{N}(\overline{P_2}-\overline{P})^2,$$

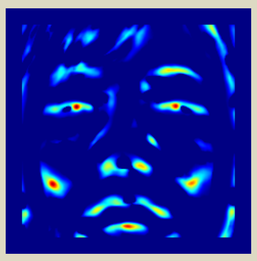
$${\sigma_T}^2 = \frac{1}{N}\sum_{P_i \in (R1 \cup R2)}(P_i-\overline{P})$$

$$= \overline{P^2} - (\overline{P})^2,$$

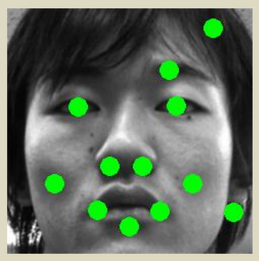


Input Image



Separability MAP



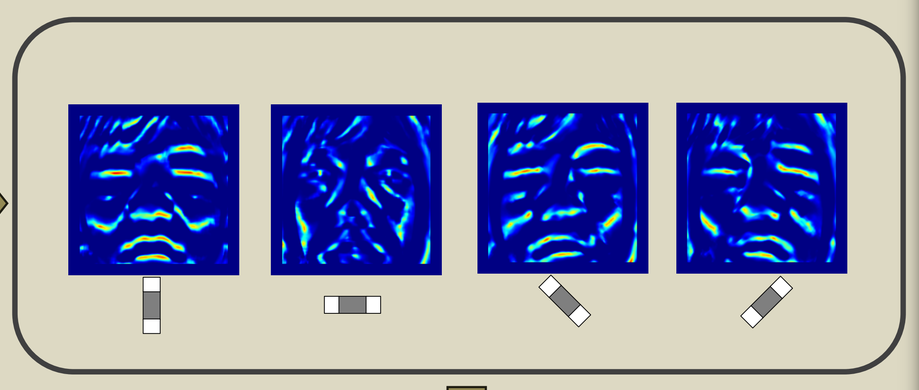
Detection result

**Computational complexity problem**

## 2: Combined Separability Filter

**To combine simple filters for detecting circular object**

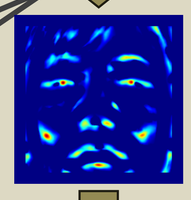
**Input image**



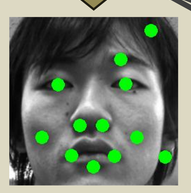
Perform four types separability filter

Combine separability maps

- Arithmetic mean: $\mu_A = \frac{1}{n}\sum_{i=1}^{n}\eta_i$
- Geometric mean: $\mu_G = \sqrt[n]{\prod_{i=1}^{n}\eta_i}$



**The combined Separability map**



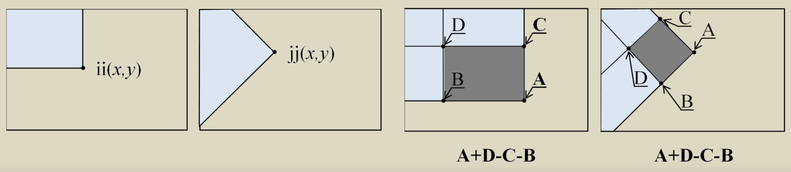
Find local maximum peaks

**Detection Result**

## 3: Fast Calculation by using Integral Images

The mean values P1, P2, P, and the mean square P2 are calculated very fast by using integral image.

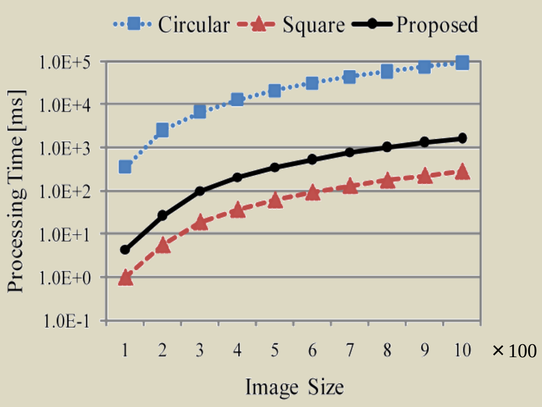
$$ii(x,y) = \sum_{\acute{x}=1}^{x}\sum_{\acute{y}=1}^{y} i(\acute{x},\acute{y})$$

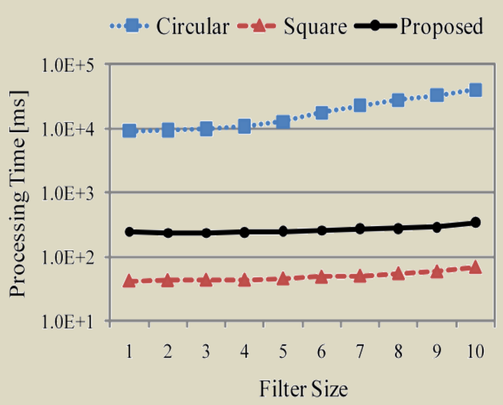



## 4: Comparison of Filters

| | Circular | Square | Combined |
|---|---|---|---|
| Filter shape | ○ | □ | ◇ |
| Speed | × | ◎ | ○ |
| Precision | ◎ | × | ○ |

## 5: Computational Complexity



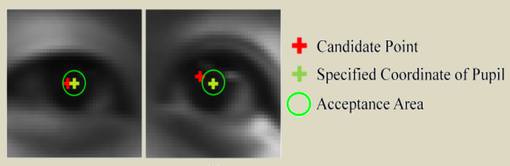



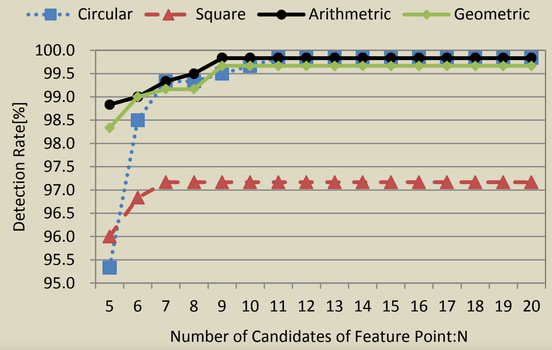

**70 times Faster than Circular Separability Filter!**

## 6: Pupil Candidate Detection

- 300 images(240x240 pixels) from 3 subjects.
- The center coordinates of pupils were specified manually, in all images.
- Pupil is detected correctly when the distance between the local maximum point and the specified true position is within 4 pixels.

| Filter type | Positioning errors (pixel) |
|---|---|
| CSF | 1.101 |
| SSF | 1.636 |
| Arithmetic mean | 1.267 |
| Geometric mean | 1.313 |




## 7: Conclusion

- We proposed a combined separability filter for detecting circular objects.
- The proposed filter has achieved a processing speed **70 times** faster than that of the conventional CSF and high positioning accuracy at the same time.