Automatic focus of cameras

Principles and a demonstration

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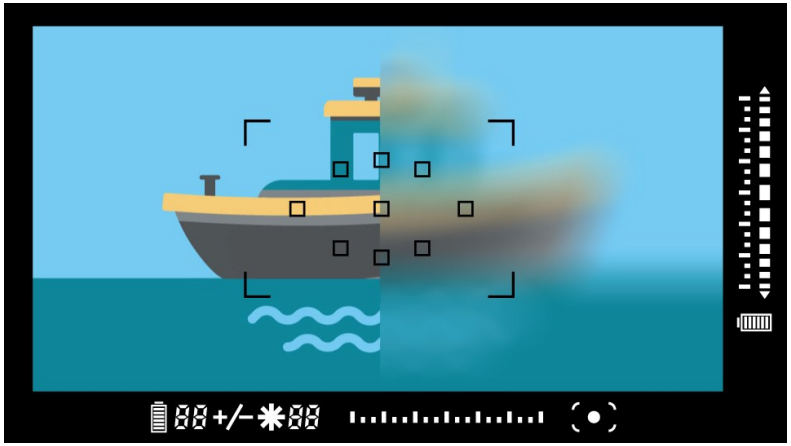
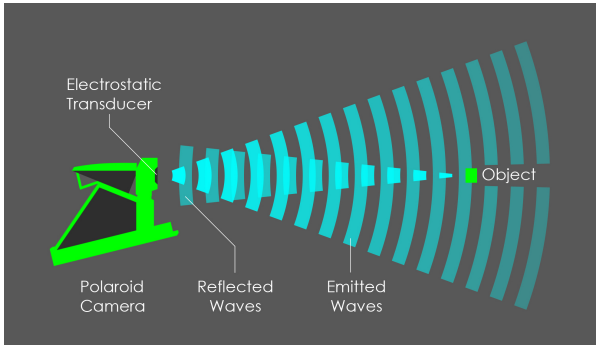
Focusing your camera



Interactive applet of AF motorics (Phase & contrast detection):
https://graphics.stanford.edu/courses/cs178/applets/autofocusPD.html

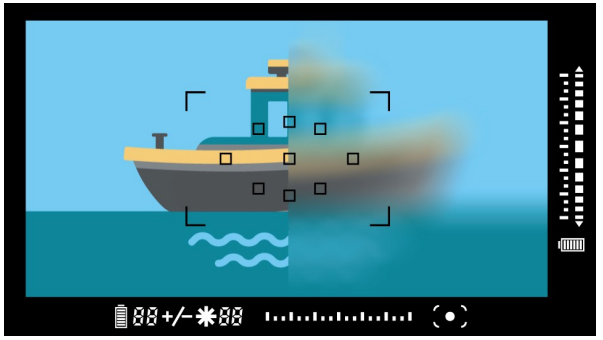
The problem of autofocusing



Active

- Sonar
- Infrared

Find distance to the object by triangulation.



Passive

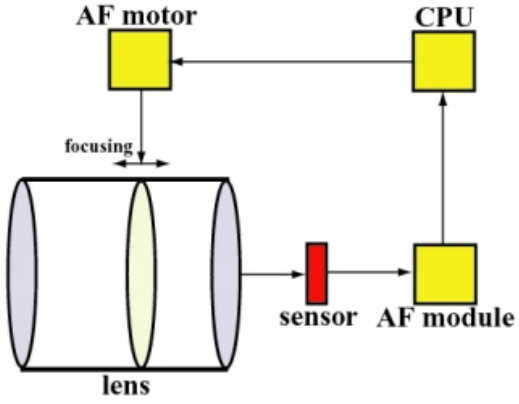
- Phase detection
- Contrast detection

Find optimal focus distance s by post-processing:

$$s = \operatorname{argmax}[F(A, s)],$$

where F is a *focus function* and A is $M \times N$-bitmap of the *active area*

Algorithms in auto-focus



Algorithm involving questions

- Where to focus? Target finding? Depth-of-the-field?
- **Is it in focus? Focus distance?**
- How to focus fast?
- How to keep the focus in a moving object?

Different focus functions

Pick one:

- **Vollath's F4 and F5**
- Log–Histogram
- Gaussian filter
- Energy of the image Laplacian
- **Variance of the image**
- Energy of the image
- Threshold
- Weighted histogram
- Hu's moments
- Tenengrad
- Absolute Tenengrad
- Discrete Cosine transformation (DCT)
- **Midfrequency-DCT**
- Total variation

Features

- Accuracy
- Speed
- Computational cost
- Robustness
- Ease of implementation
- ...

Perez *et al*, 2012, DOI: 10.1002/cyto.a.22020

Different focus functions

Suppose a $M \times N$ bitmap A of the active area, now $g(i,j)$ is the *gray value* at (i,j) and $\bar{g}$ is the global average of g.

Variance of the image (VAR)

$$F_{var} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (g(i,j) - \bar{g})^2 , \tag{1}$$

Vollath's F5[1] (F5)

$$F_{voll} = \sum_{i=1}^{M-1} \sum_{j=1}^{N} g(i,j) \cdot g(i+1,j) - MN\bar{g}^2, \tag{2}$$

Midfrequency Discrete Cosine Transform[2] (MDCT)

$$F_{var} = \sum_{i=1}^{M} \sum_{j=1}^{N} (g(i,j) \otimes O_m)^2 , O_m = \begin{bmatrix} 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 \end{bmatrix} \tag{3}$$

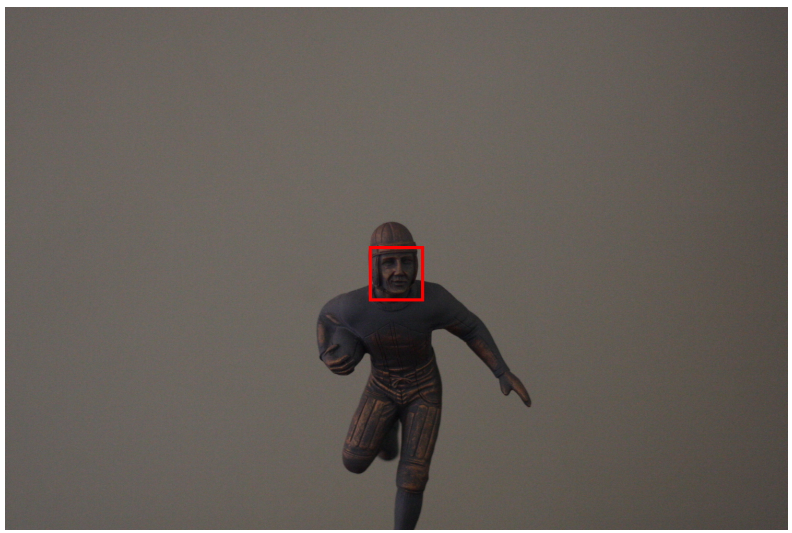
[1] D. Vollath, 1987, DOI: 10.1111/j.1365-2818.1988.tb04620.x

[2] S. Lee *et al*, 2008, DOI: 10.1109/TCSVT.2008.924105

Try this at home

Idea

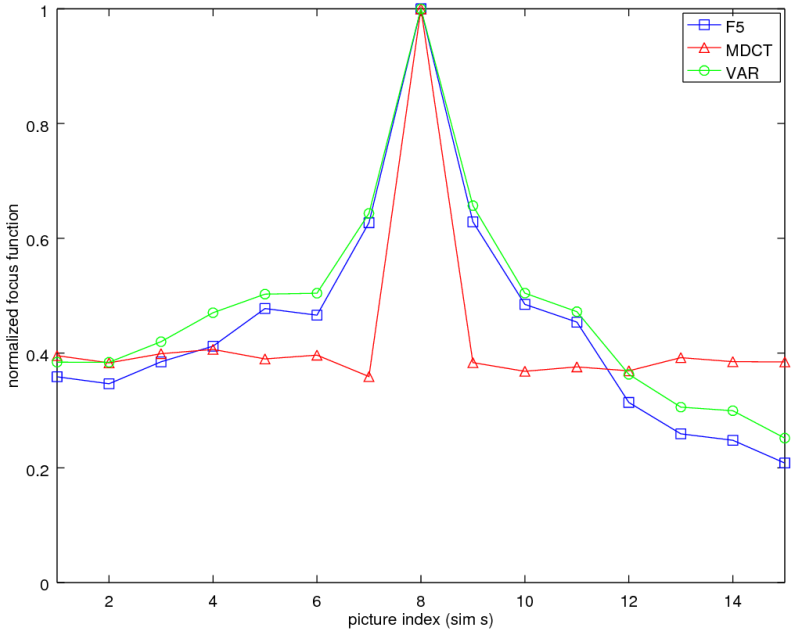
- Setup target at distance x
- Take T pictures at different focus distances s
- Digitize and convert to bitmap
- Crop to the active area (M-by-N matrix)
- Compute focus function F for each picture
- Choose optimal $s = \mathrm{argmax}(F(s))$



Implementation

- $x \sim 1.0m$
- $T = 15$
- Load JPEG:s to GNU Octave
- $M = 100$, $N = 100$ right at the center of the target

Computing focus functions



Notes and conclusions

- Small inconsistencies in aiming
- All functions agree on the max
- MDCT has the best contrast, but is the least linear

Summary

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- Autofocus is an essential feature in optical imaging systems, such as **cameras and microscopes**
- **Active** AF is based on sensors, **passive** on image processing
- Different (passive) Focus functions exist, and here was a demonstration of **Vollath's F5** and **Variance of the image** and **Midfrequency Discrete cosine transformation**
- Real-time AF system is often a **proprietary combination** of these technologies