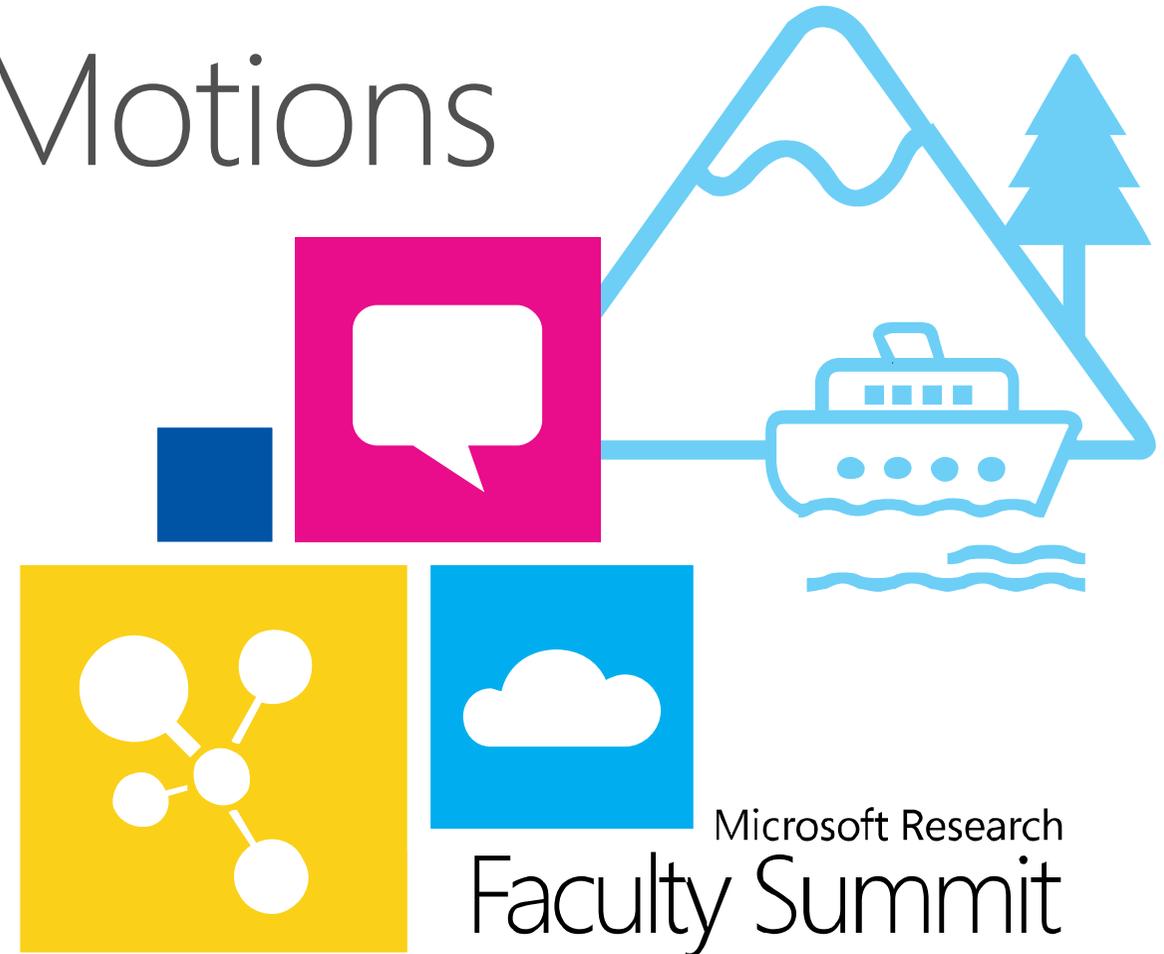


Microsoft Research
Faculty
Summit
2013



A Big World of Tiny Motions

William T. Freeman
Professor, Assoc. Dept. Head,
Dept. Elect. Eng. and Computer Science
Massachusetts Institute of
Technology



A big world of tiny motions.

- Joint work with Michael Rubinstein, Hao Yu, Eugene Hsu, Neal Wadhwa, John Guttag, Fredo Durand. SIGGRAPH, 2012, 2013

Michael Rubinstein
summer intern,
Microsoft Research Seattle: 2011,
Microsoft Research New England: 2012
Microsoft Research PhD Fellowship, 2012-2013



Imperceptible Changes in the World



Respiratory motion

Buildings swaying
in wind



Pulse and Blood flow



Magnifying Glass for Temporal Variations



Pulse and Blood flow

Magnifying Glass for Temporal Variations



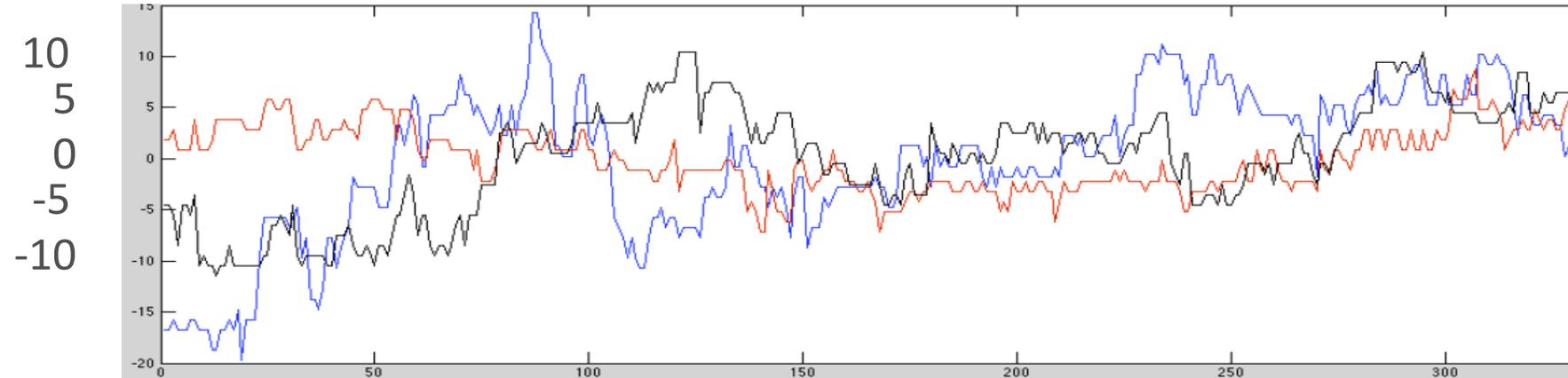
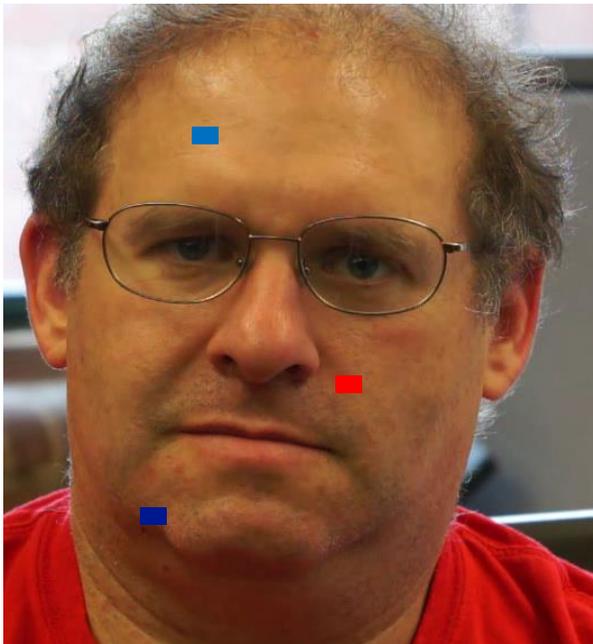
Respiratory motion



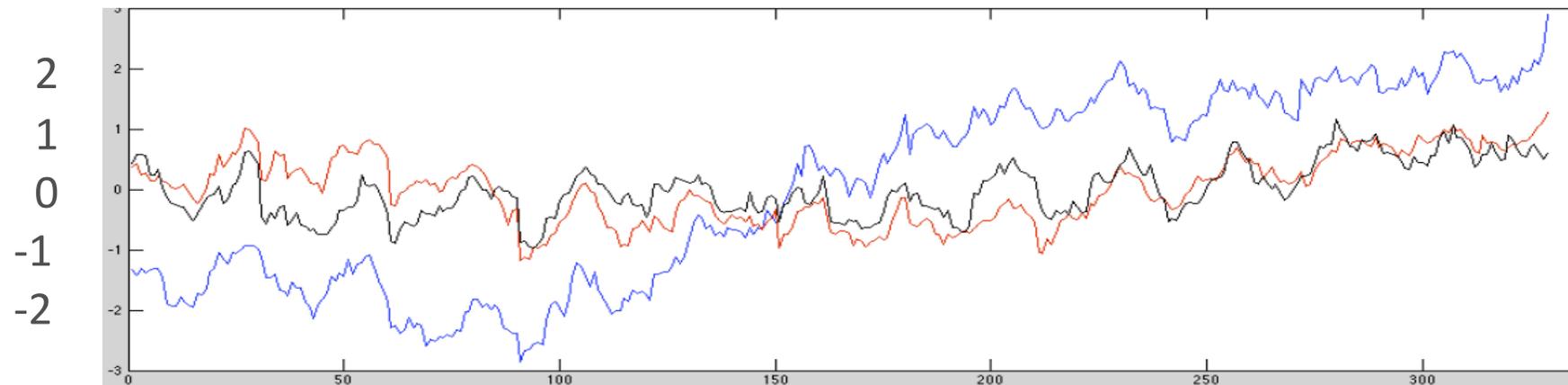
Pulse and Blood flow

Amplifying Subtle Color Variations

- 1. Average spatially to overcome sensor and quantization noise



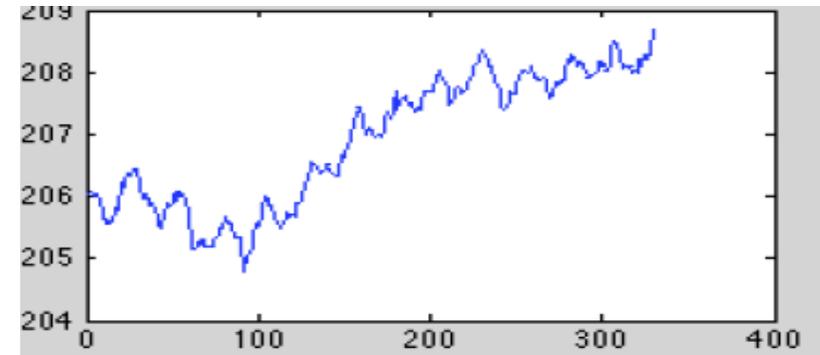
Luminance traces for 3 image locations (zero mean)



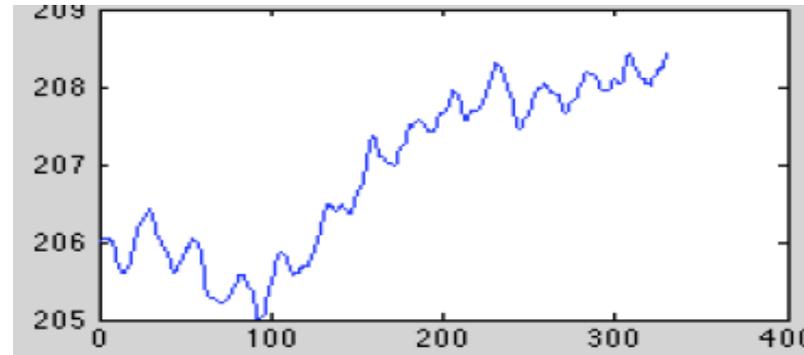
Spatial average in those locations

Amplifying Subtle Color Variations

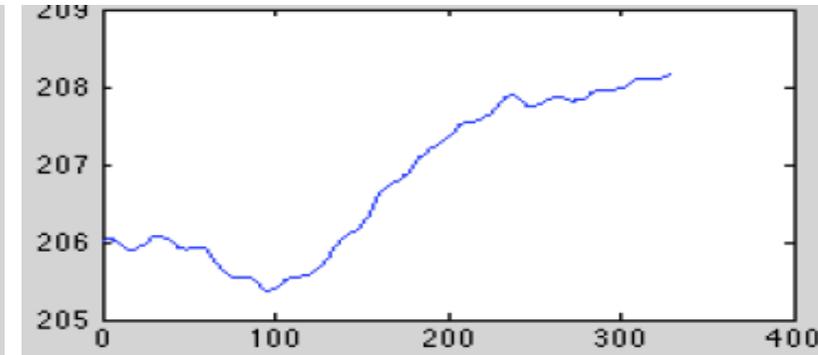
- 2. Filter Temporally



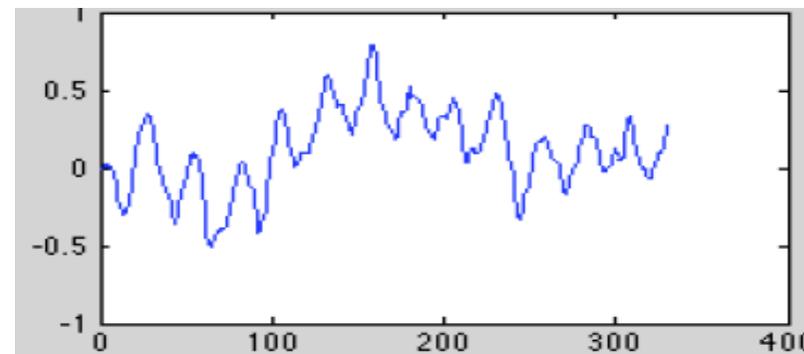
Luminance trace



IIR1 [.4,.6]



IIR2 [.05,.95]



Temporally bandpassed trace



Color Amplification Results



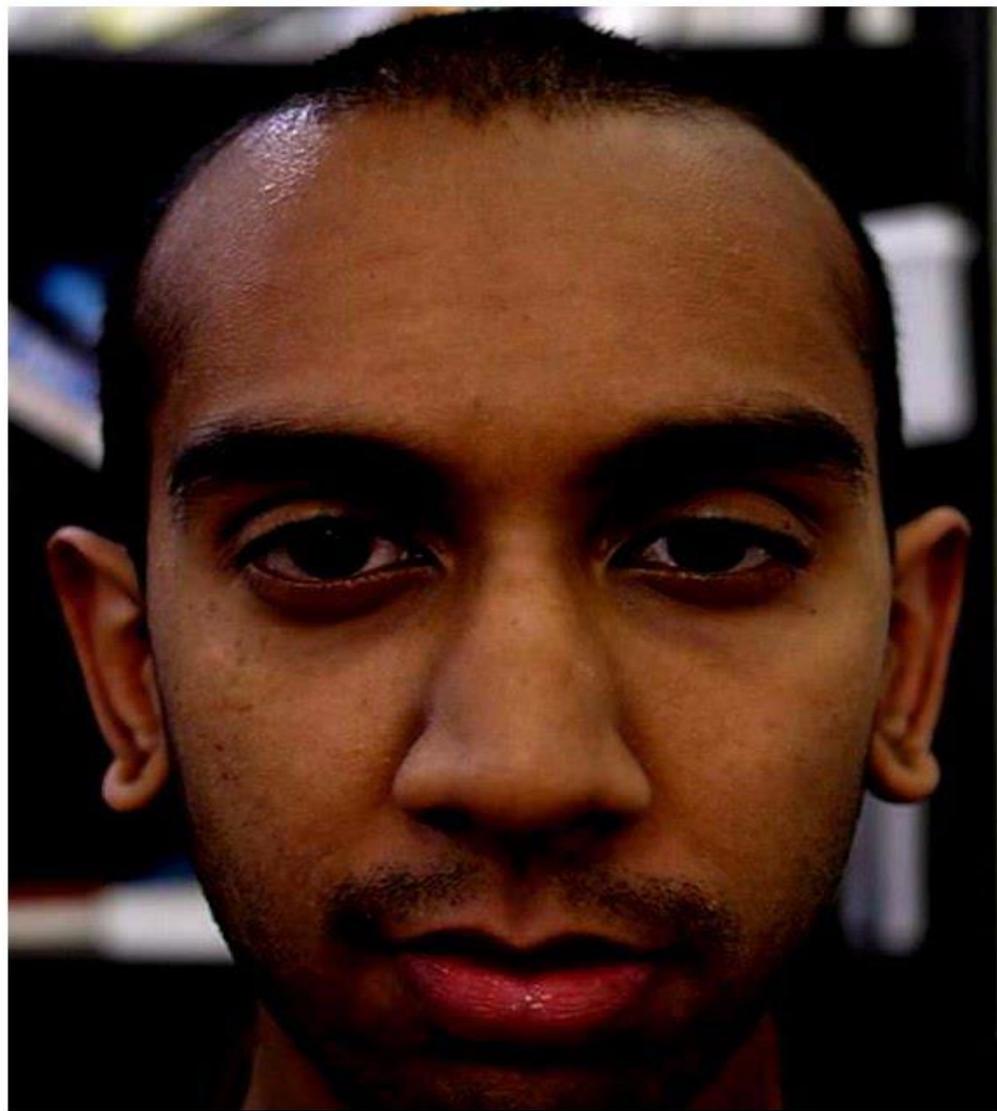
Source



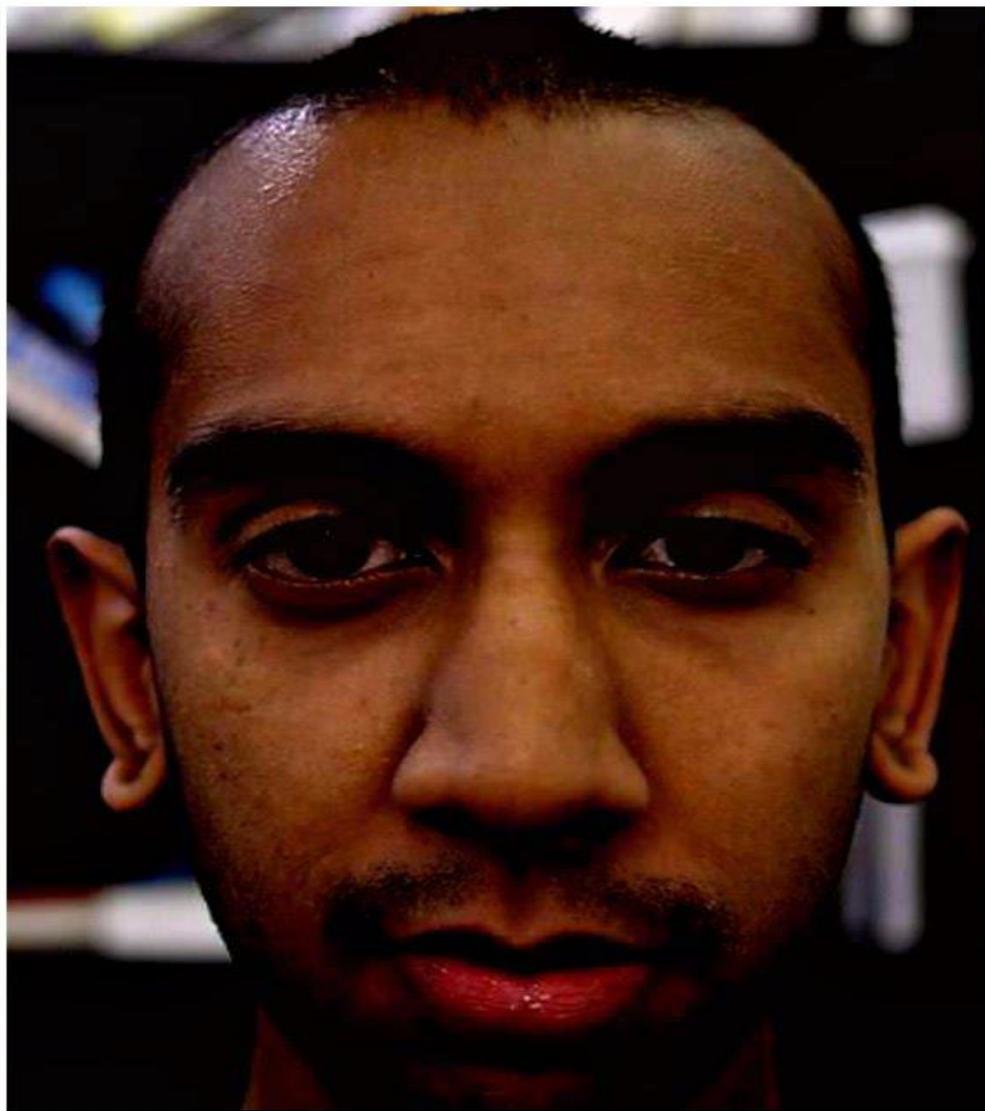
Color-amplified (x100)
0.83-1 Hz (50-60 bpm)
(ideal filtering)



Color Amplification Results



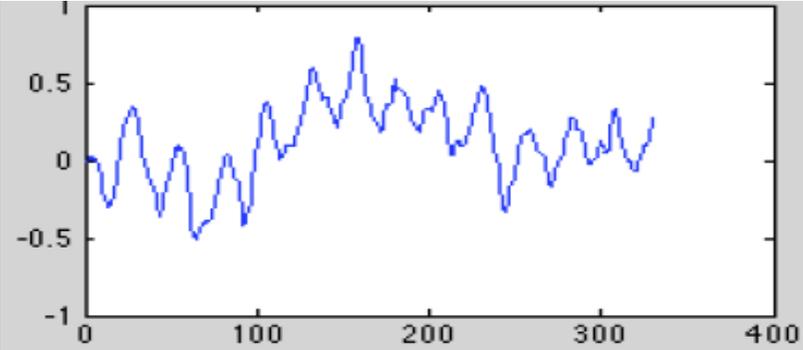
Source



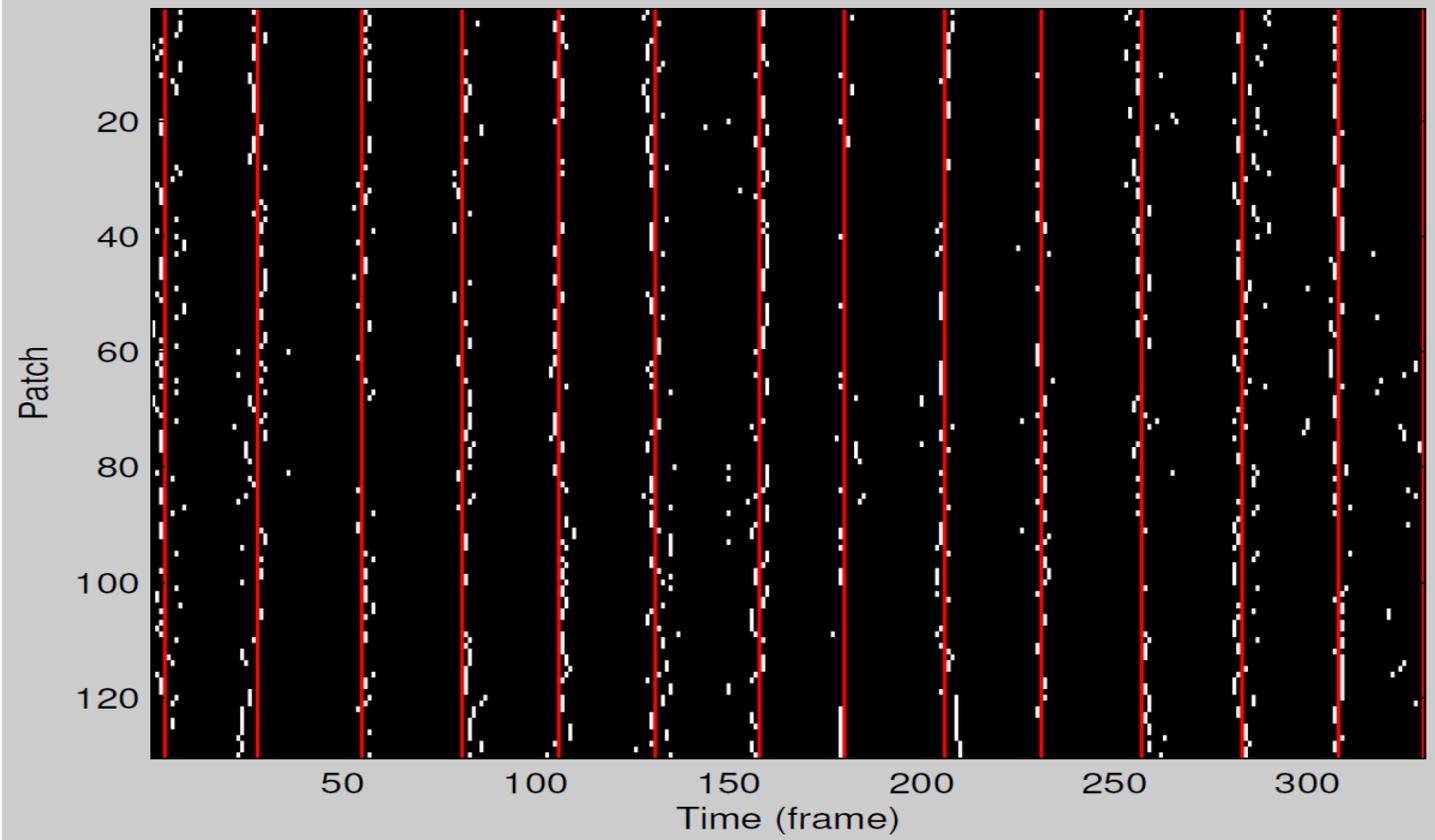
Color-amplified (x120)
0.83-1 Hz (50-60 bpm)



Heart Rate Extraction



Temporally bandpassed trace
(one patch)



Pulse locations



Heart Rate Extraction

The image is a composite showing the process of heart rate extraction from a newborn. It is divided into three main sections:

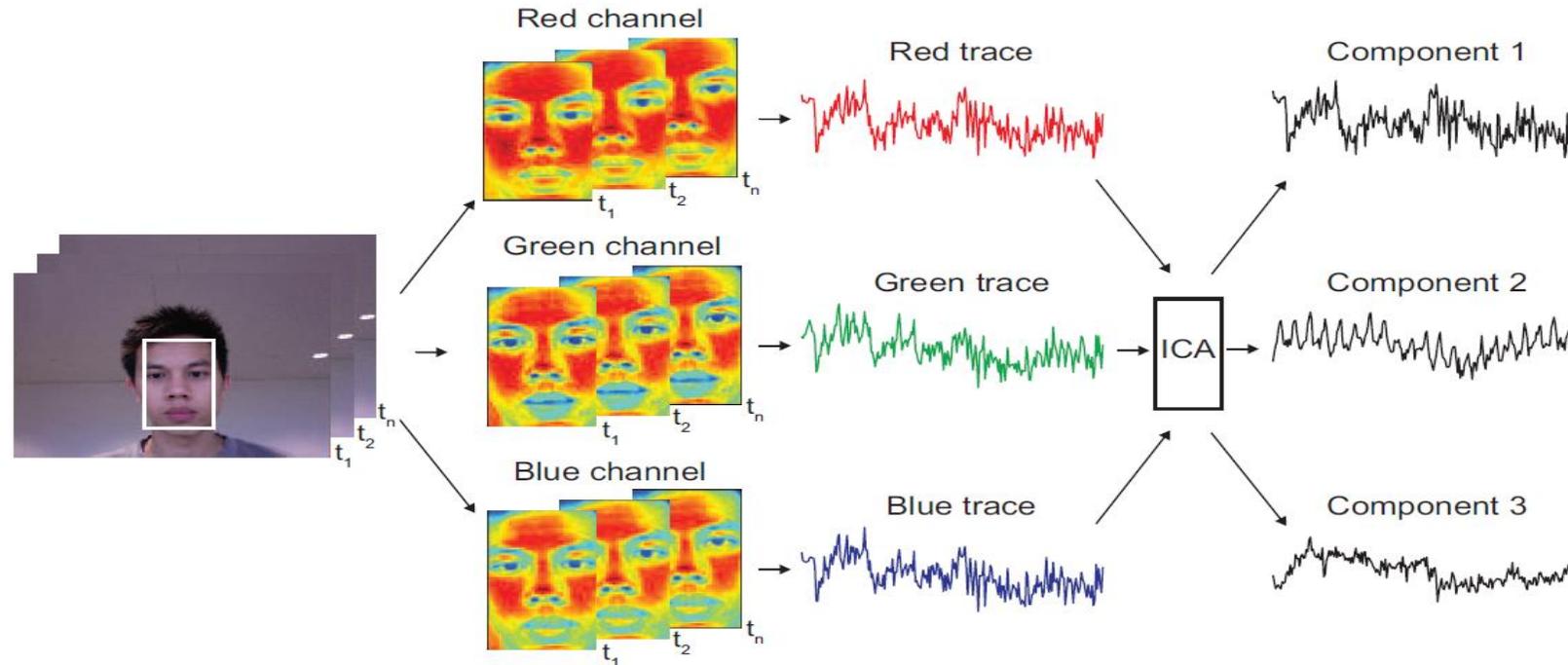
- Source:** A photograph of a newborn baby lying in a hospital bed, wearing a pink outfit and having an orange sensor attached to their chest. A color calibration chart and a handwritten note with the number '4' are visible in the background. Below the photo is the text "Source" and "(Courtesy of Winchester Hospital. Do not copy)".
- Hospital monitor:** A photograph of a hospital monitor displaying vital signs. A green arrow points to the ECG waveform on the screen. The monitor shows a heart rate of 152, a respiratory rate of 46, and a pulse of 99. Below the photo is the text "Hospital monitor".
- Color-amplified (x150):** A large photograph of the same newborn baby. Overlaid on the top left of this photo is a signal processing diagram. It shows a "Bandpass signal + peaks (pulse)" as a red waveform with sharp peaks. Below it, an "Estimated heart rate" is shown as a red dot next to the text "146 bpm". Below the photo is the text "Color-amplified (x150)".

Thanks to Dr. Donna Brezinski and the Winchester Hospital staff

2.33-2.67 Hz (140-160 bpm)



Related Work on Pulse Detection from Videos



Poh, McDuff and Picard, *Non-contact, automated cardiac pulse measurements using video imaging and blind source separation*, 2010

Face recognition
and tracking



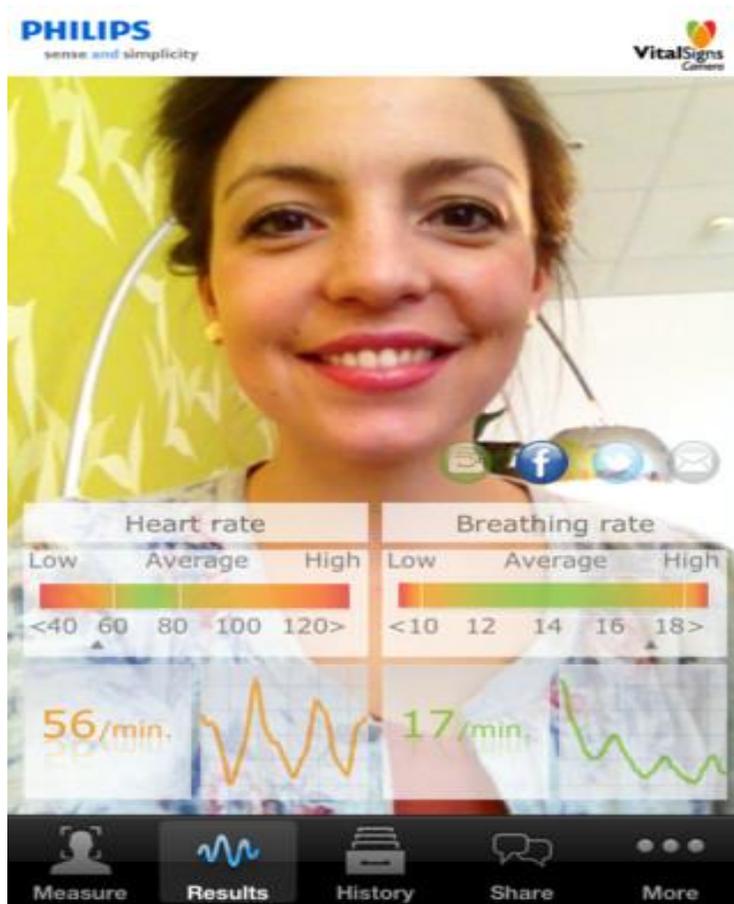
RGB averaged
over ROI
(single number)



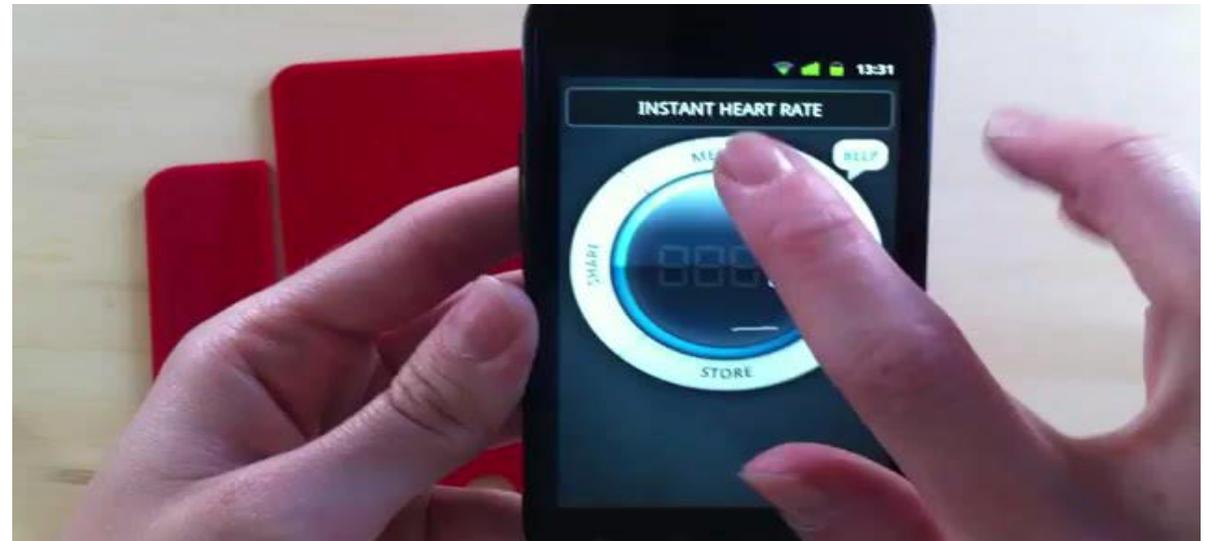
Use ICA to find
signal sources



Cell Phone Apps...



"Vital Signs Camera" – Philips (proprietary)



"Instant Heart Rate" for Android Photoplethysmography (PPG)



The extra motion with the color amplification puzzled us



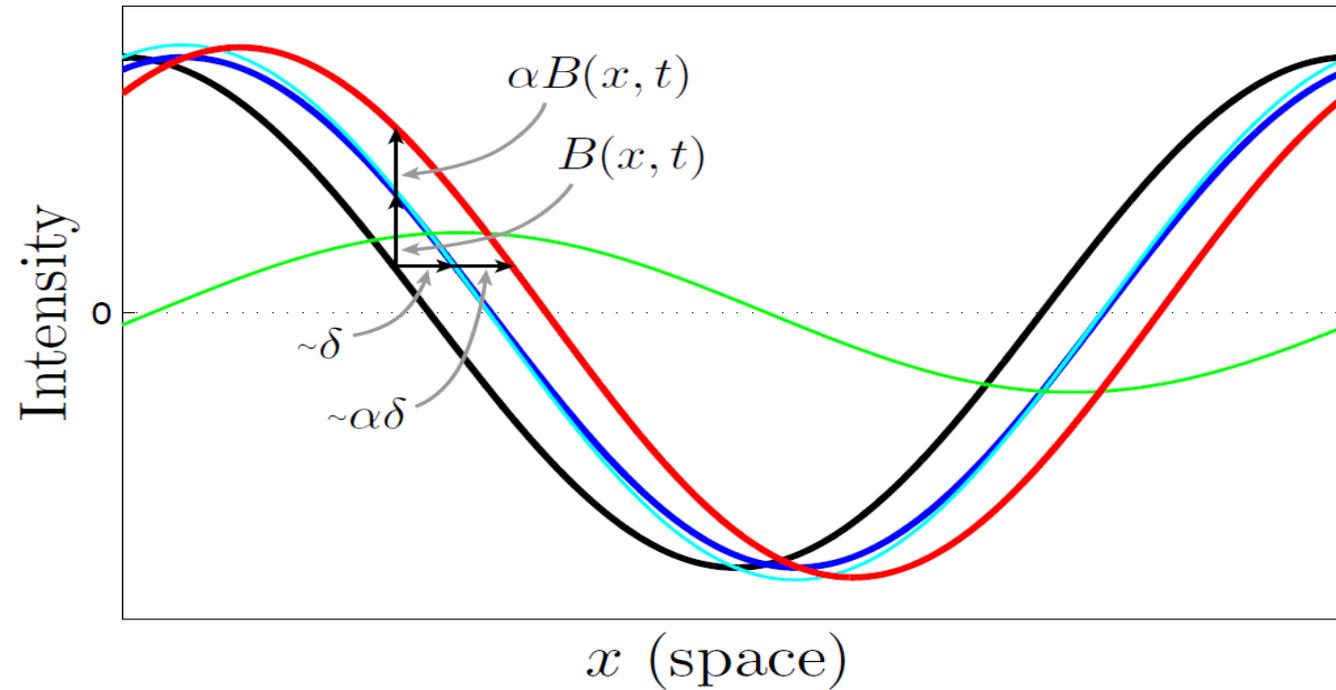
Source



Color-amplified (x100)
0.83-1 Hz (50-60 bpm)
(ideal filtering)



Motion Magnification via Temporal Filtering



— $f(x)$ — $f(x + \delta)$ — $f(x) + \delta \frac{\partial f(x)}{\partial x}$ — $B(x, t)$ — $f(x) + (1 + \alpha)B(x, t)$



Linearized motion magnification

Rigid translation

$$I(x, t) = f(x + \delta(t))$$

Assume small translation
relative to image structures

$$I(x, t) = f(x) + \delta(t) \frac{\partial f(x)}{\partial x}$$

Amplify temporally
bandpassed signal

$$\hat{I}(x, t) = I(x, t) + (\alpha - 1)B_t[I(x, t)]$$

Modified signal

$$= f(x) + \alpha \delta(t) \frac{\partial f(x)}{\partial x}$$

Assume the amplified translation
is still small relative to image
structures

$$= f(x + \alpha \delta(t))$$



Where we expect this to break down

Let's look at it for $f(x)$ being a sinusoid,

Linearized

$$\begin{aligned}\cos(\omega x + \alpha\omega\delta) &\approx \cos(\omega x) - \alpha\omega\delta \sin(\omega x) \\ &= \cos(\omega x)\cos(\alpha\omega\delta) - \sin(\omega x)\sin(\alpha\omega\delta)\end{aligned}$$

Exact translation by $\alpha\omega\delta$

For the motion magnification approximation to hold:

$$\cos(\alpha\omega\delta) = 1 \quad \lambda = \frac{2\pi}{\omega}$$

$$\sin(\alpha\omega\delta) = \alpha\omega\delta$$

Condition required for those conditions to be approximately true:

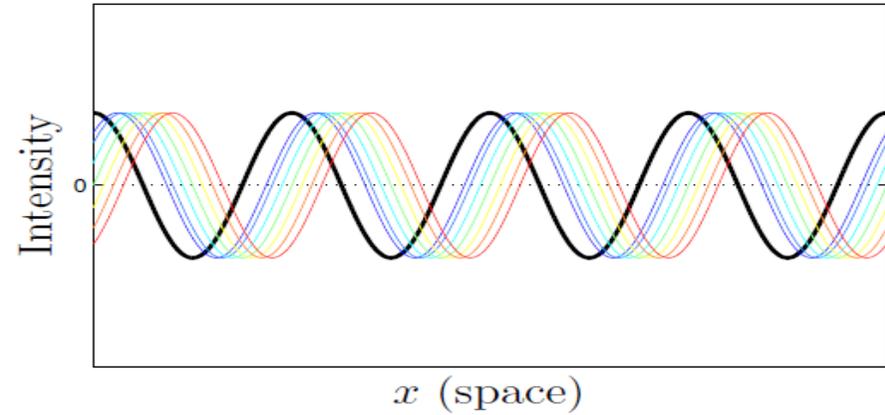
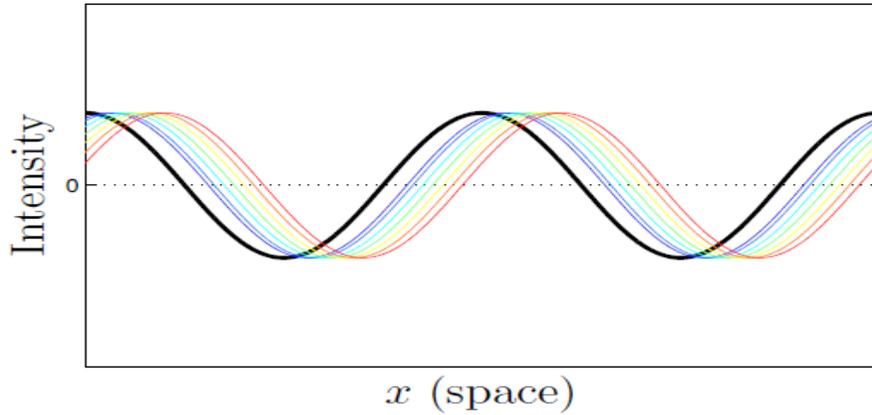
$$\sin\left(\frac{\pi}{4}\right) = 0.9 \frac{\pi}{4}$$

$$\alpha\omega\delta < \frac{\pi}{4}$$

true displacement
spatial frequency
magnification amount

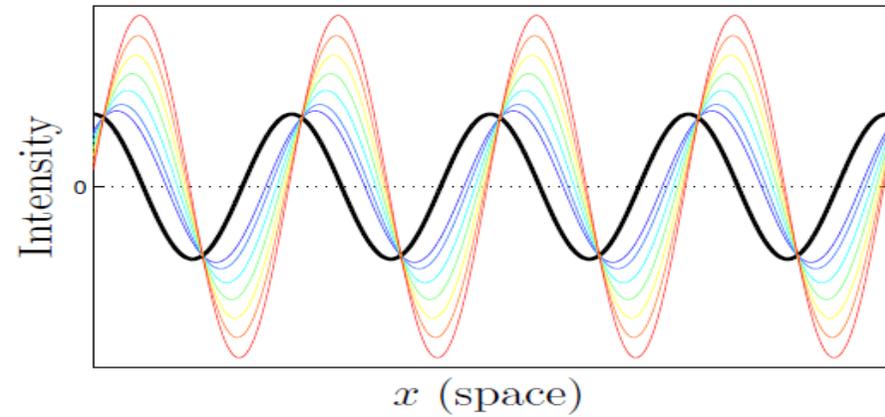
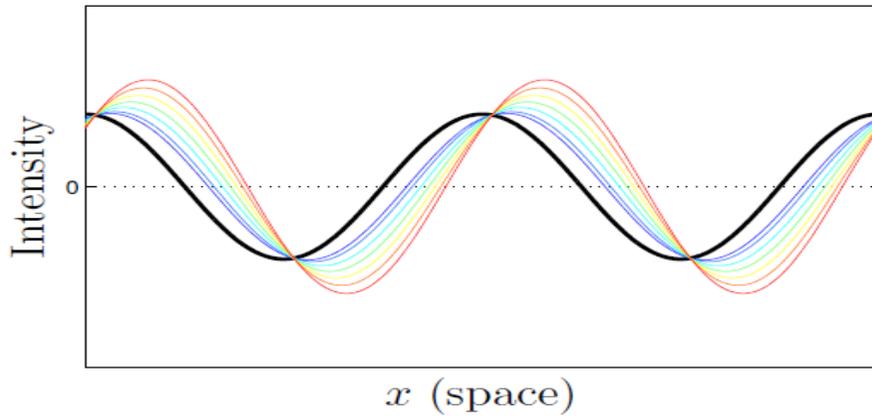


Synthetic 1D Examples



(a) True motion amplification: $\hat{I}(x, t) = f(x + (1 + \alpha)\delta(t))$.

— $\alpha = 0.2$ — $\alpha = 0.5$ — $\alpha = 1.0$ — $\alpha = 1.5$ — $\alpha = 2.0$ — $\alpha = 2.5$ — $\alpha = 3.0$

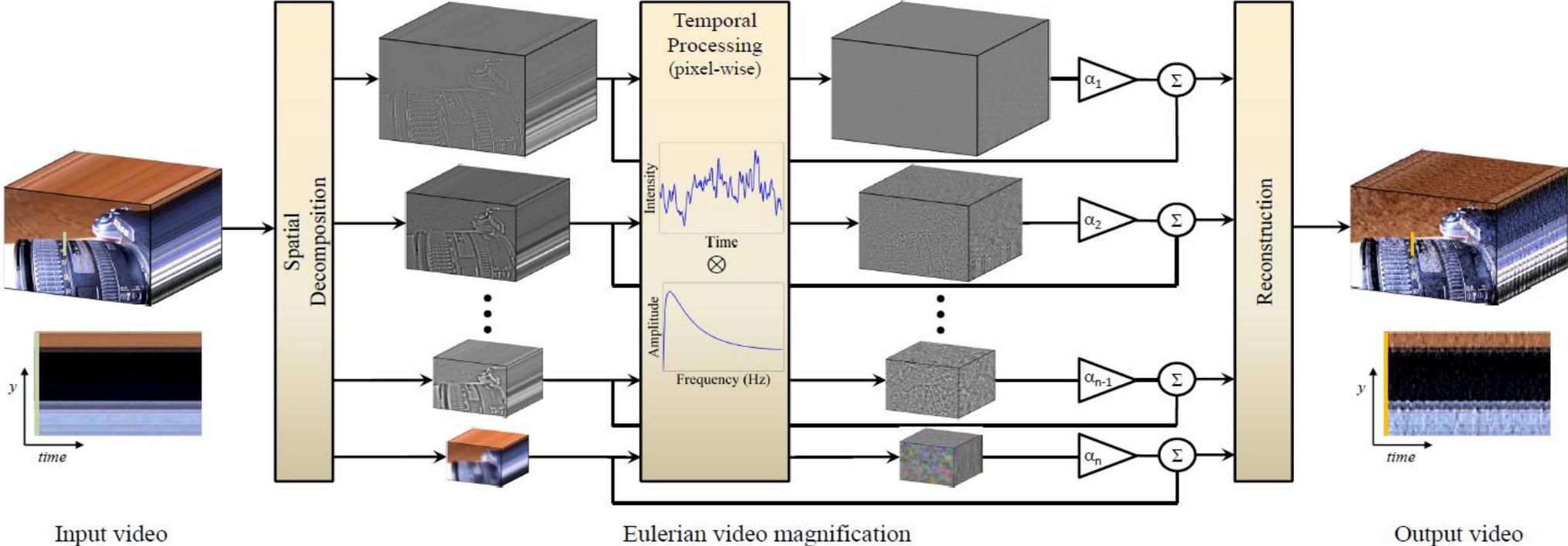


(b) Motion amplification via temporal filtering:

$$\tilde{I}(x, t) = I(x, t) + \alpha B(x, t).$$



System Overview



Amplify spatial frequencies where approximation holds, otherwise fail toward zero

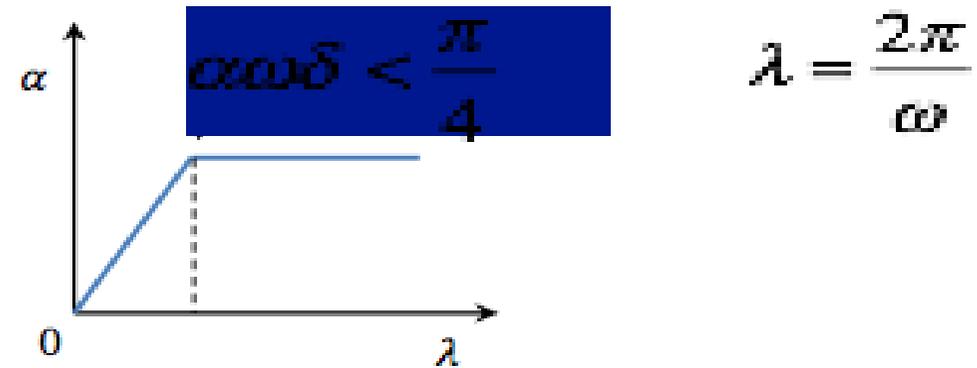


Figure 6: Amplification factor, α , as function of spatial wavelength λ , for amplifying motion. The amplification factor is fixed to α for spatial bands that are within our derived bound (Eq. 14), and is attenuated linearly for higher spatial frequencies.





Source



Motion-magnified (3.6-6.2 Hz, x60)

Demo

The Eulerizer

Processed Video



Original Video



Amplification 30

Low cut-off 0.4 Hz

High cut-off 4 Hz

Exit

The image shows a software interface for 'The Eulerizer'. It features two side-by-side video windows. The left window, labeled 'Processed Video', displays a train interior with a stylized, painterly or 'Eulerized' visual effect. The right window, labeled 'Original Video', shows the same train interior in its original, clear state. Below the video windows are three control sliders: 'Amplification' (set to 30), 'Low cut-off' (set to 0.4 Hz), and 'High cut-off' (set to 4 Hz). An 'Exit' button is located in the bottom right corner.



Motion Magnification Results



Source



Motion-magnified (0.4-3 Hz, x10)

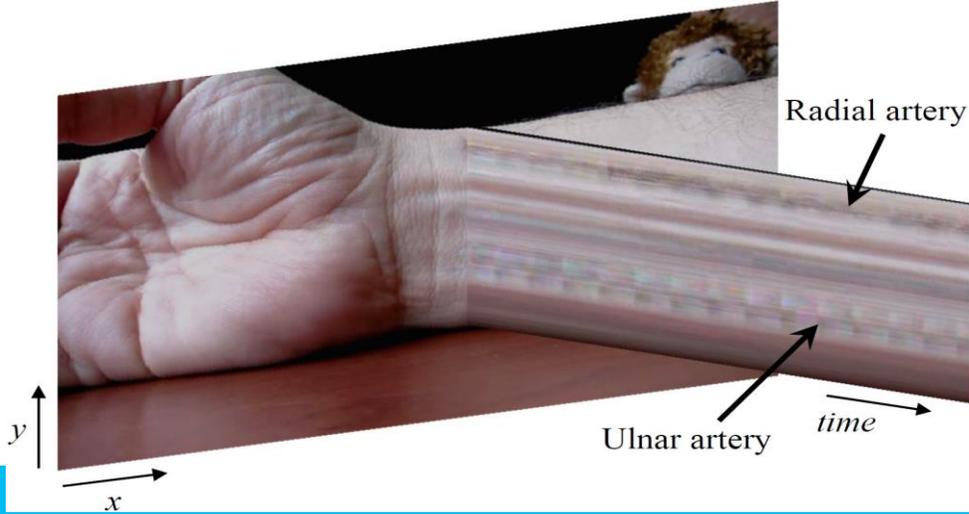
Motion Magnification



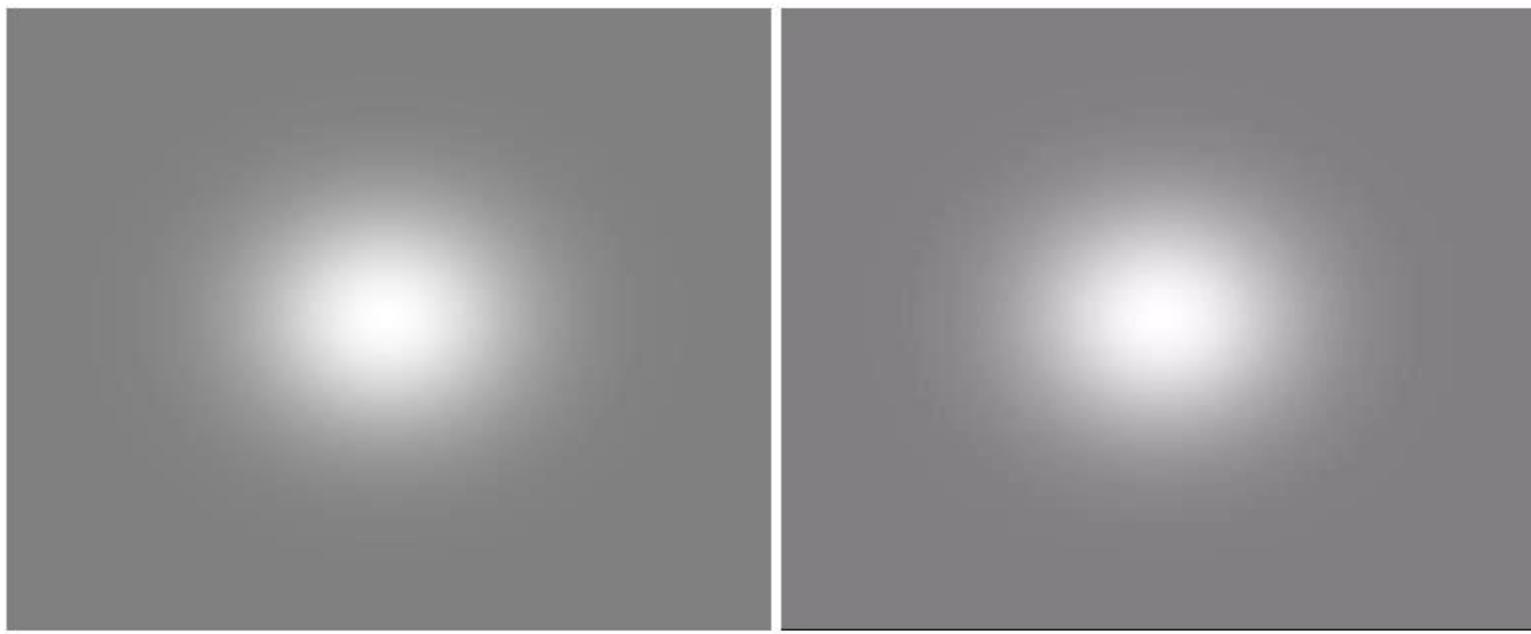
Source



Motion-magnified (0.4-3 Hz, x10)



Synthetic 2D Example



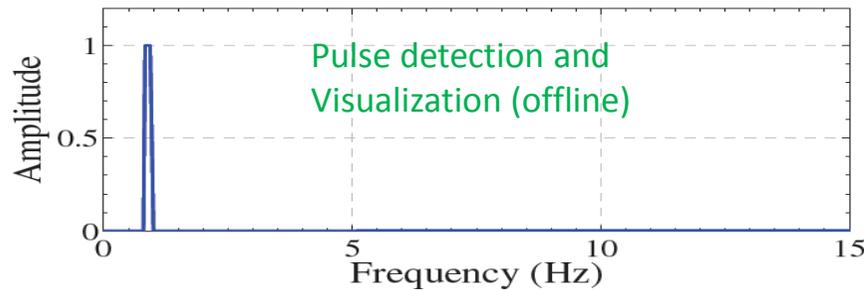
Source

Motion-magnified

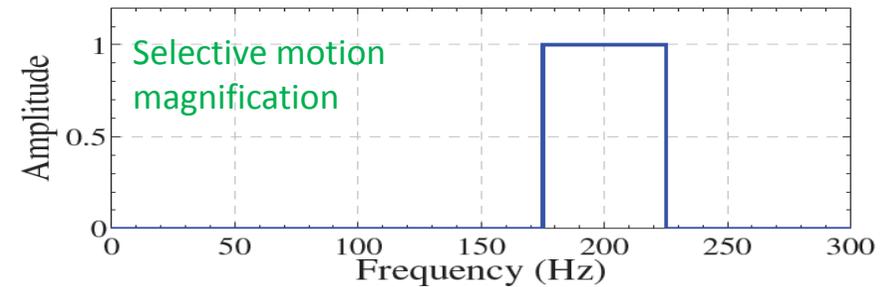


Temporal Filters

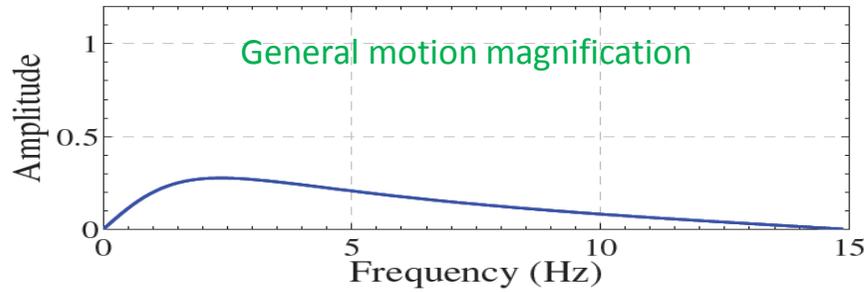
- Mostly application dependent
 - Configurable by the user
- Some of the filters we used (and their applications):



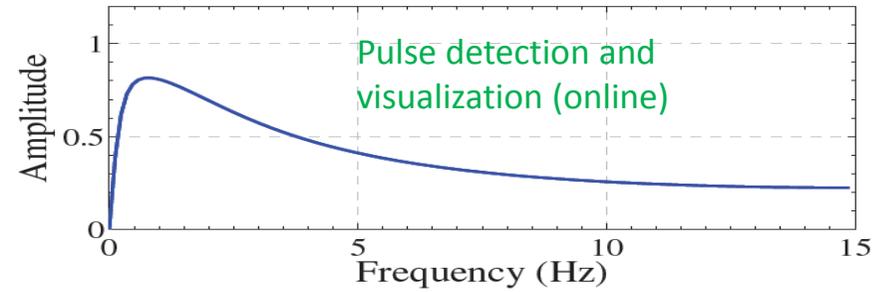
(a) Ideal 0.8-1 Hz (*face*)



(b) Ideal 175-225 Hz (*guitar*)



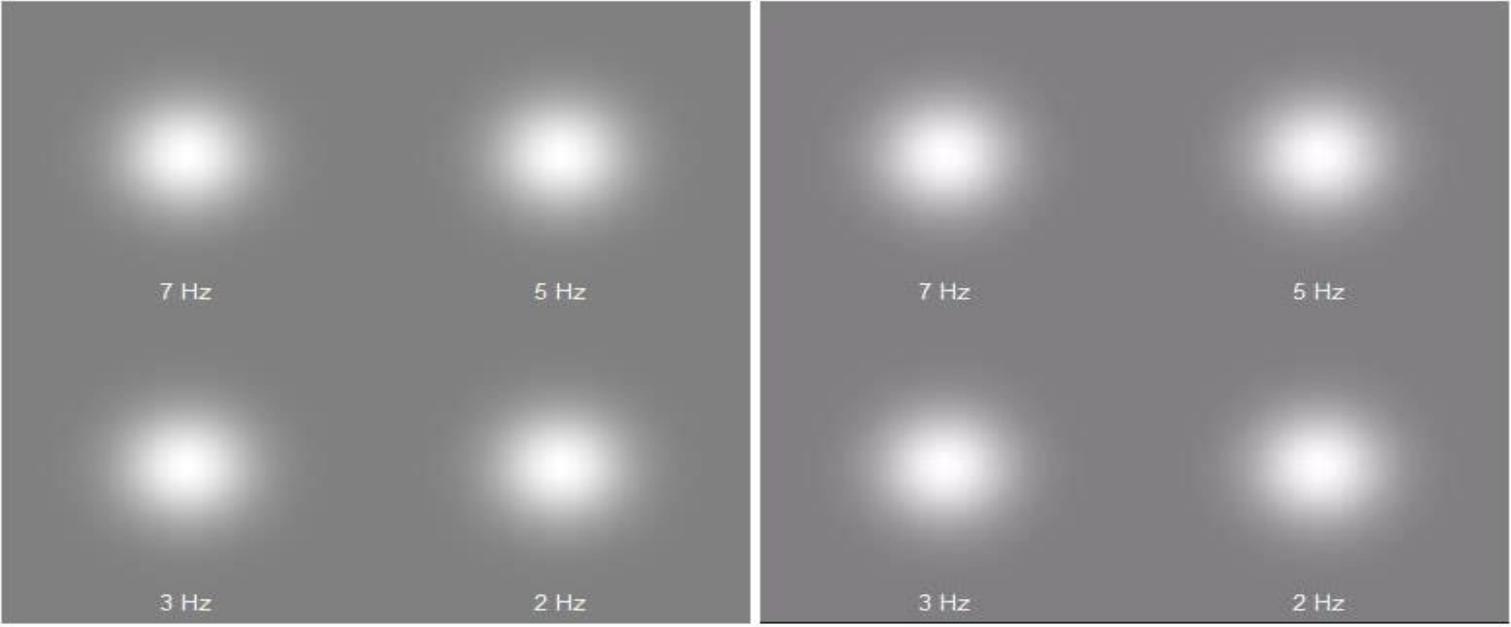
(c) Butterworth 3.6-6.2 Hz (*subway*)



(d) Second-order IIR (pulse detection)



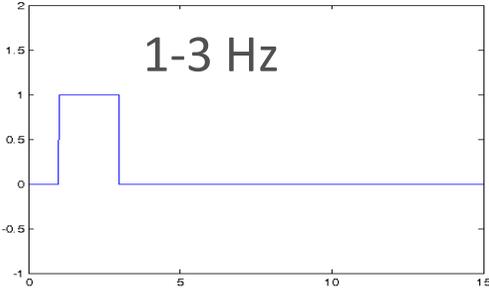
Selective Motion Magnification



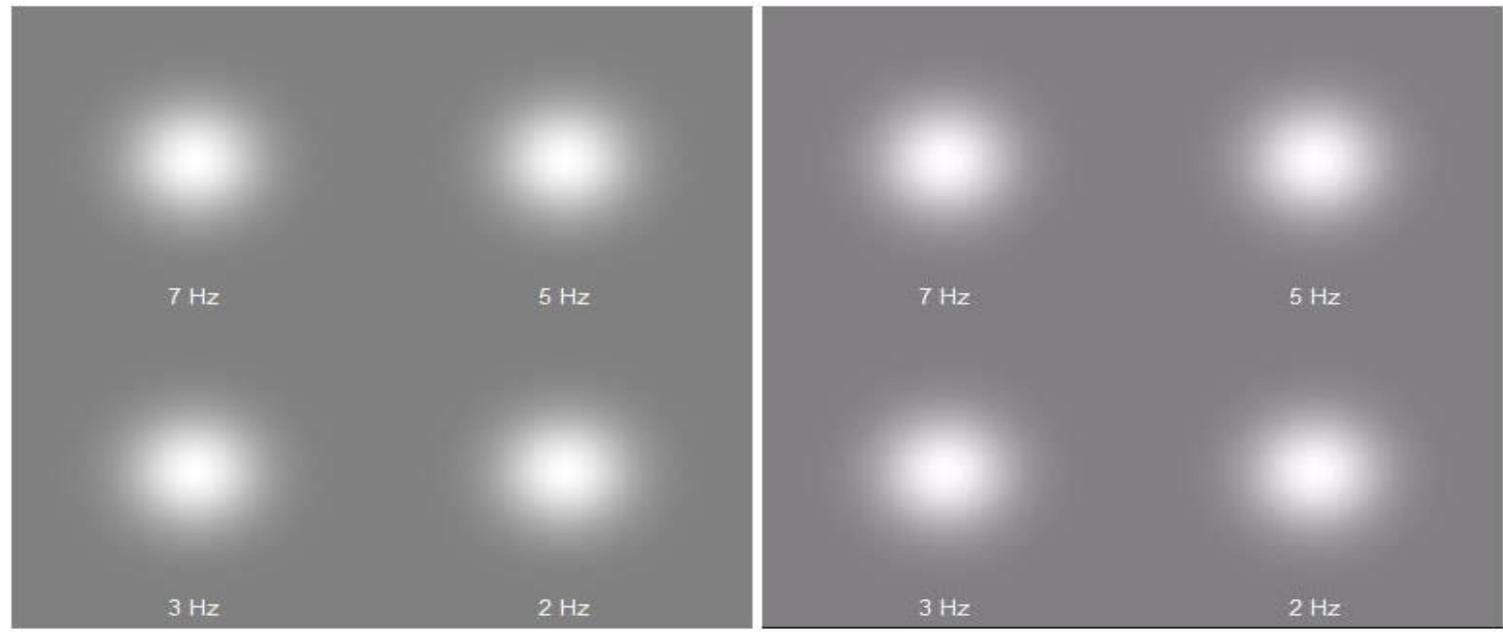
Source

Motion-magnified (2 Hz)

Temporal filter:



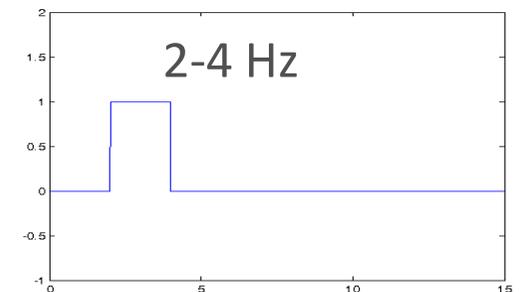
Selective Motion Magnification



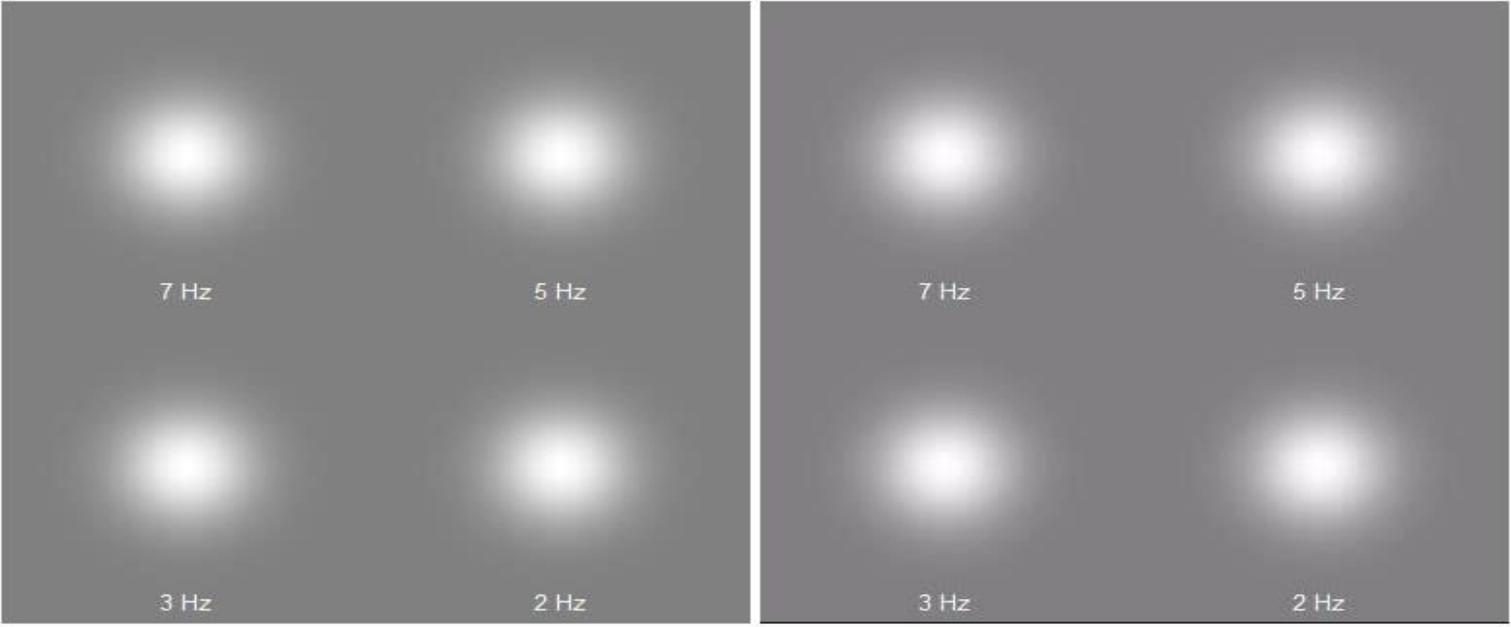
Source

Motion-magnified (3 Hz)

Temporal filter:



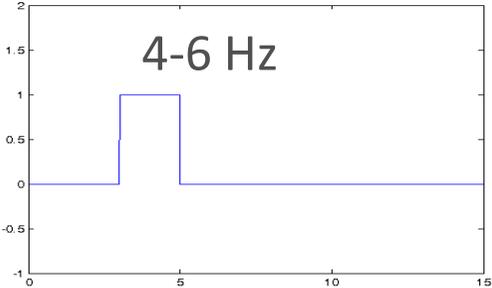
Selective Motion Magnification



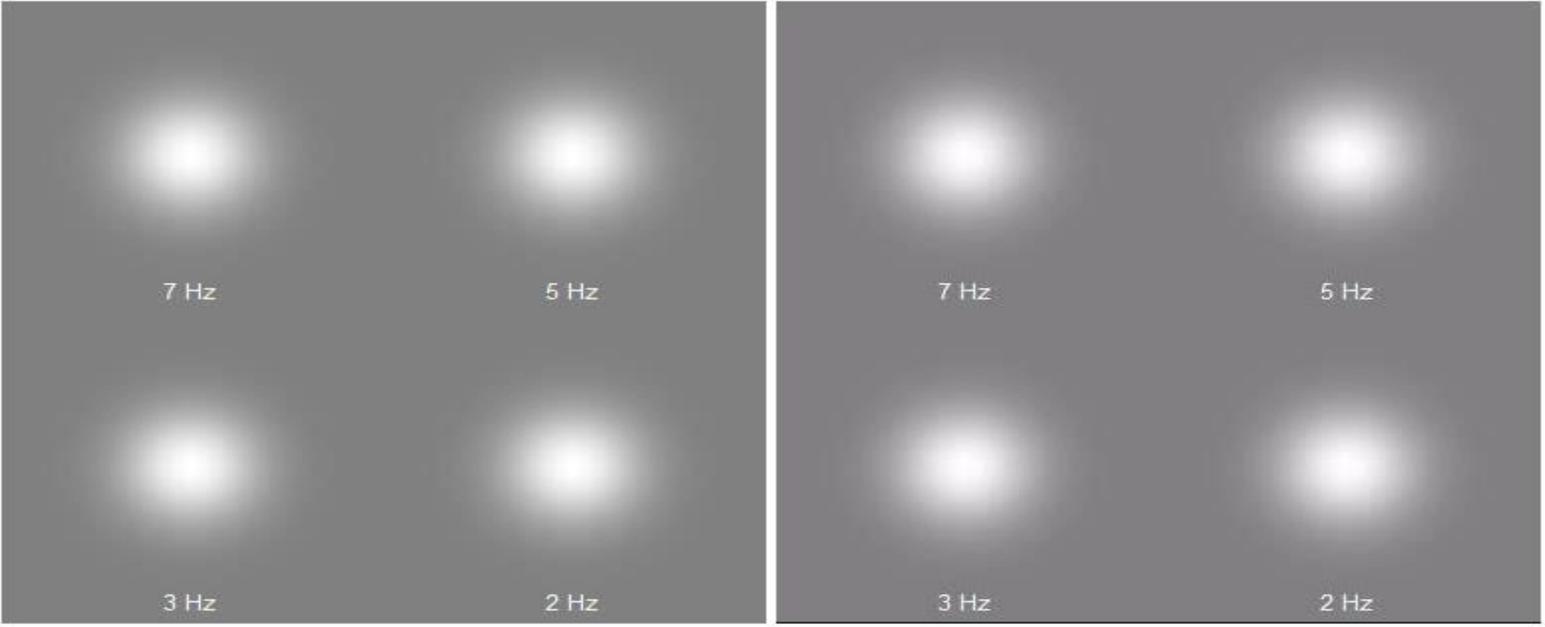
Source

Motion-magnified (5 Hz)

Temporal filter:



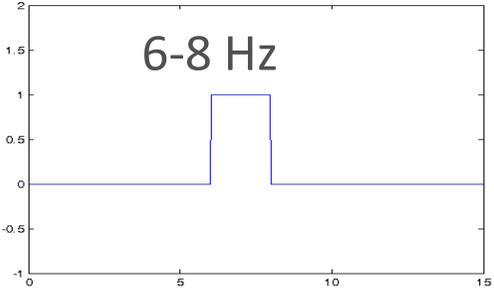
Selective Motion Magnification



Source

Motion-magnified (7 Hz)

Temporal filter:



Selective Motion Magnification in Natural Videos

Source
(600 fps)



72-92 Hz
Amplified



← Low E (82.4 Hz)

100-120 Hz
Amplified



← A (110 Hz)



Motion Magnification Results



Source (300 fps)



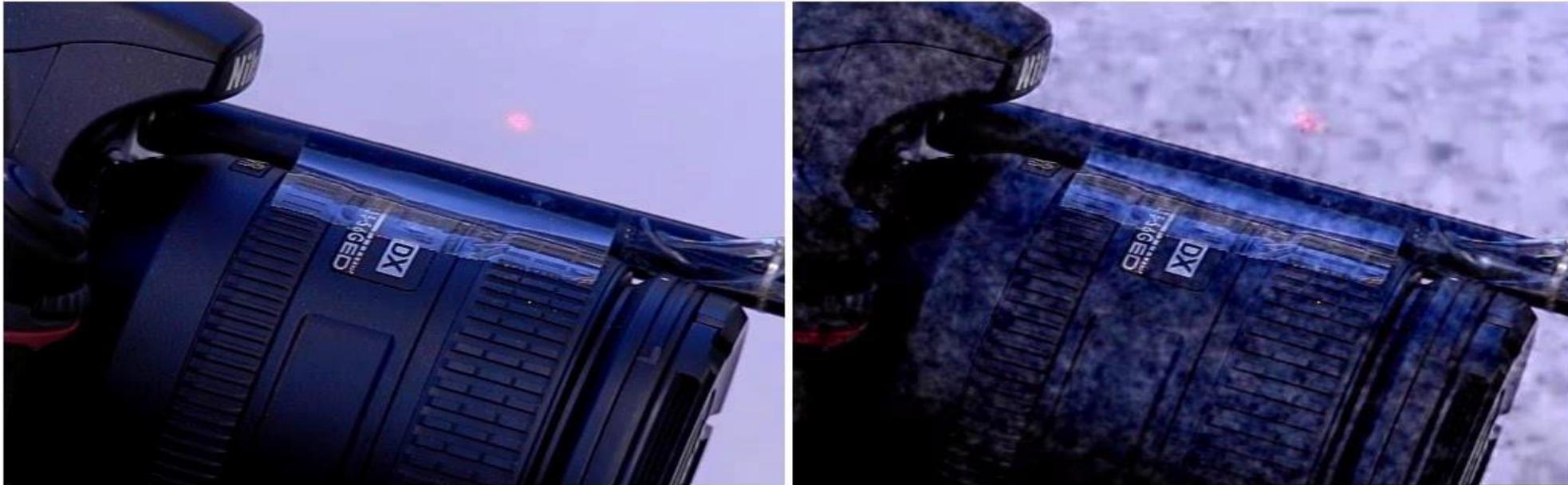
Motion-magnified (45-100 Hz, x100)



DSLR Controlled Setup

Laser pointer

Reflected laser point



Source (300 fps)

Motion-magnified (45-100 Hz, x100)

Same DSLR camera
(Nikon D400)

Standard A4 sheet



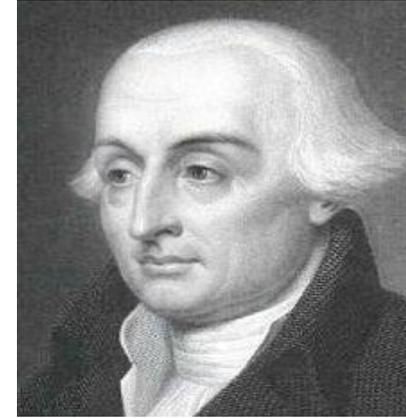
Eulerian vs. Lagrangian Motion Magnification

Leonhard Euler



VS

Joseph Louis Lagrange



- Works better for smooth structures
- Supports smaller amplification factors
- Real time processing
- Unified framework to amplify spatial motion and purely temporal changes (e.g. heart pulse)
- Supports frequency-based processing and selective amplification

- Works better for point features
- Supports larger amplification factors
- Computationally intensive
- Optical flow may be inaccurate



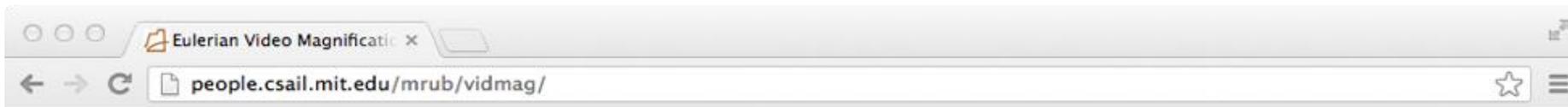
Bruce Wayne's Pulse



Batman Begins (2005), courtesy of Warner Bros. Pictures



Eulerian Video Magnification in the wild



Code

[Matlab](#) (2 MB, v1.1 2013-03-02) - reproduces all the results in the paper (see README.txt for details).

This code is provided for non-commercial research purposes only. By downloading and using the code, you are consenting to be bound by all terms of [this software release agreement](#). Contact the authors if you wish to use the code commercially.

Please cite our paper if you use any part of the code or data supplied on this web page.

*** This work is patent pending**

Data

All videos are in MPEG-4 format and encoded using H.264.



[source result](#)



[source result](#)



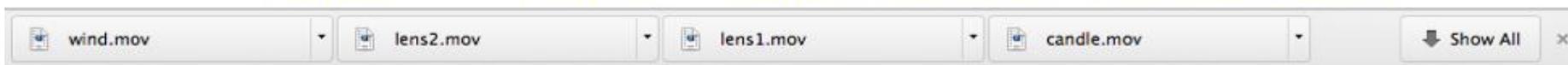
[source result](#)



[source result \(color\)](#)



[source result \(low E\) result \(A\)](#)



VideoScope by Quanta Research Cambridge



Home | **Quanta** | Projects | MIT CSAIL | People | Jobs | Press | Fun | Contact | Videoscope

User ID: **0b7f2be4-b8b6-464c-9ead-d68d10999661** | Current video: **baby2** [Return to chooser](#) | [Help](#)

Set frame rate (fps) [?]

Select magnification type [?] Color Motion

Set frequency range (Hz) [?]

Set amplification [?]

Select filter type [?] Ideal Butterworth IIR

Description (optional) [?]

Show additional options...

Terms of Service [?] I agree to the [Terms of Service](#).

Process the video [?] Status: **Not running.**

We're interested in your feedback. If you have comments or suggestions, have an interesting application in mind, or would like to join our mailing list to learn about updates and new capabilities, [click here](#) or send email to videoscope@qrclab.com.

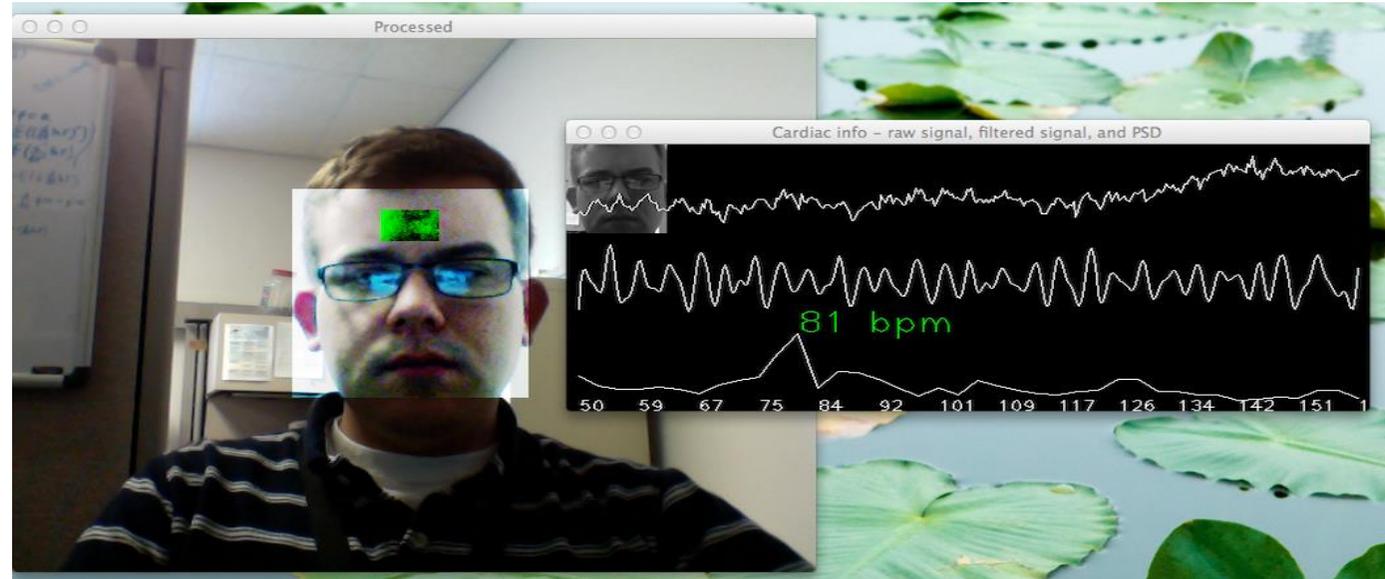
Original Video



0:29

Independent (Real-time) Ports

“webcam-pulse-detector”
(Python + openCV)
+tracking



“VAmp - Video Amplifier”
(Java)



EVM in the Wild: Pregnancy



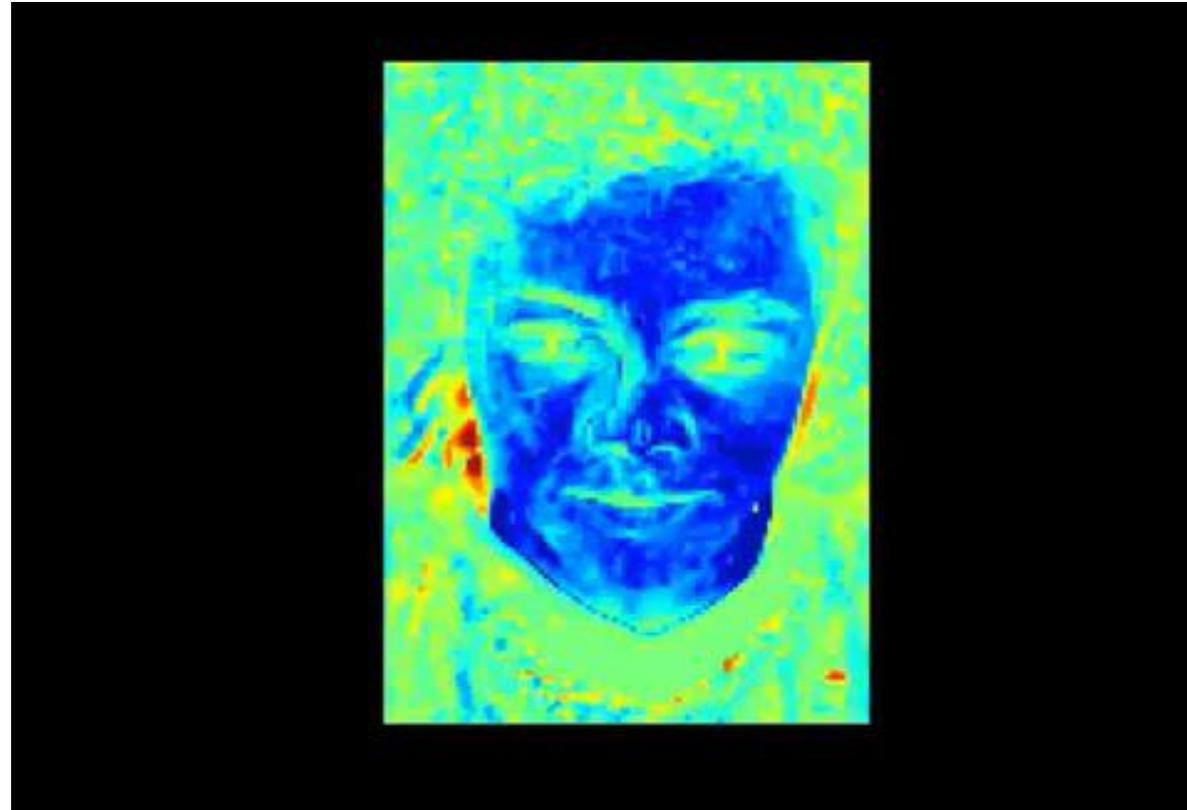
Original



Processed



EVM in the Wild: Blood flow Visualization



Red = high blood volume
Blue = low blood volume

Institute for Biomedical Engineering, Dresden Germany



EVM in the Wild: Guinea Pig!



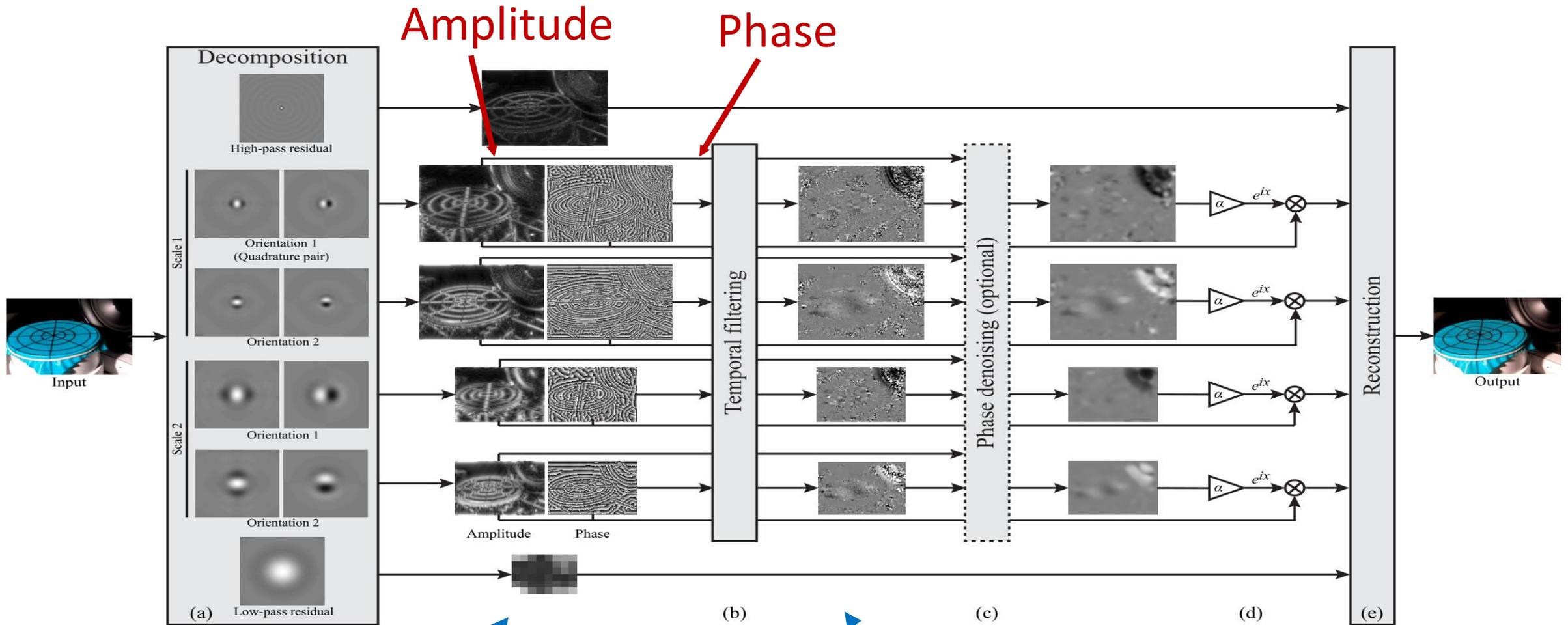
Source

Motion-magnified

“SuperCreaturefan”: “Guinea pig Tiffany is the first rodent on Earth to undergo Eulerian Video Magnification.”



Phase-based Pipeline (SIGGRAPH'13)



Complex steerable pyramid
[Simoncelli and Freeman 1995]

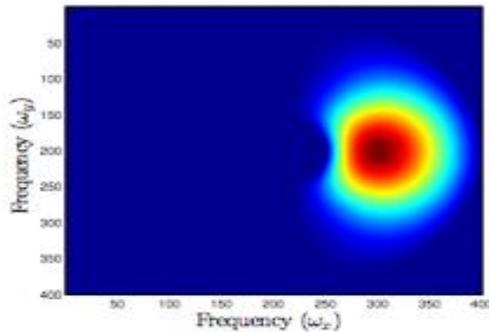
Temporal filtering on **phases**



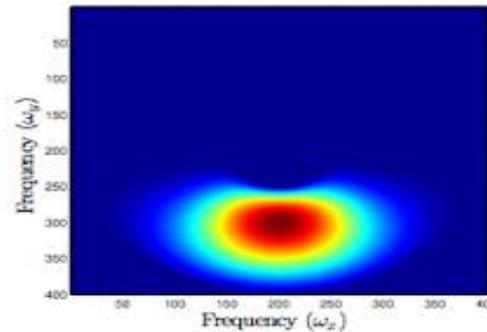
Steerable Pyramid (Freeman and Adelson 1991)

- ▶ Set of filters to locally decompose image into different spatial bands
- ▶ Filters indexed by scale ω and orientation θ
- ▶ Transfer functions partition frequency domain
- ▶ Apply filters $T_{\omega,\theta}$ to image $I(x, y)$ by doing

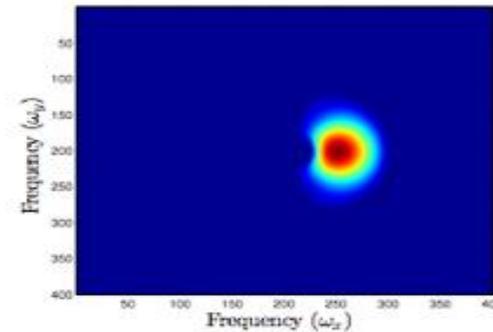
$$S_{\omega,\theta} = \underbrace{\mathcal{F}^{-1}}_{\text{To Primal Basis}} \left\{ \underbrace{T_{\omega,\theta}}_{\text{Isolate components}} \times \underbrace{\mathcal{F}\{I\}}_{\text{To Fourier Basis}} \right\}$$



$$\theta = 0, \omega = 100$$



$$\theta = \frac{\pi}{2}, \omega = 100$$

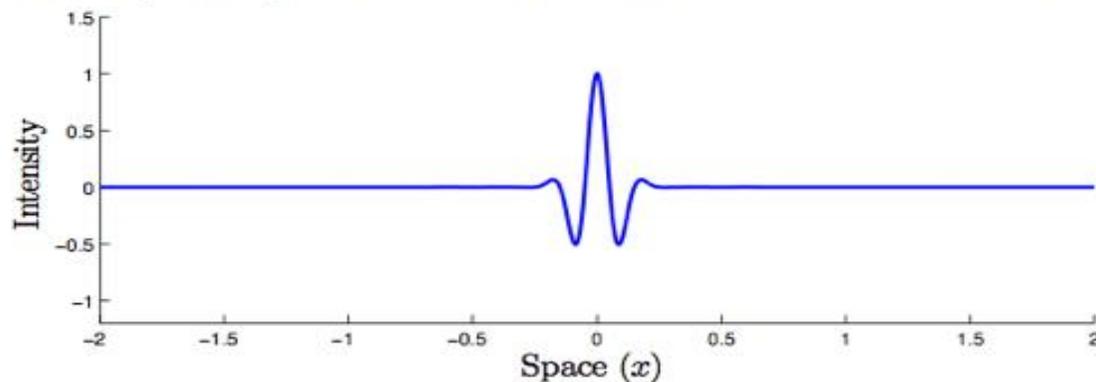


$$\theta = 0, \omega = 50$$

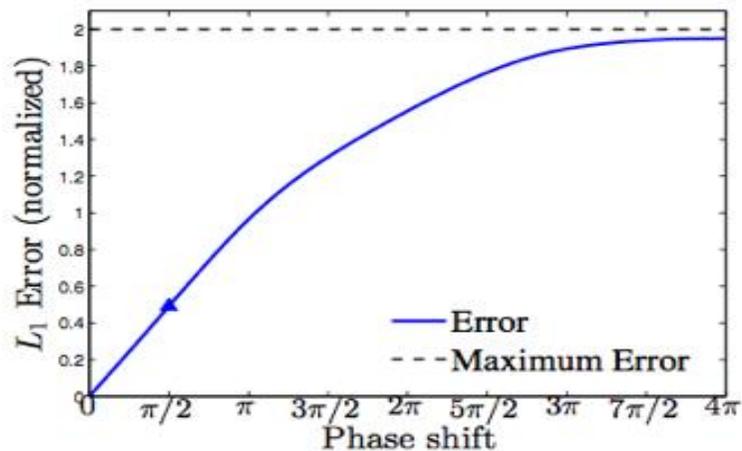
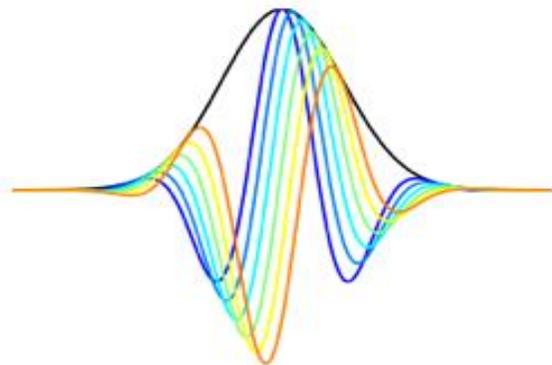
Sample Steerable Pyramid Transfer Functions $T_{\omega,\theta}$

Decomposition into Wavelets

- ▶ Locally, image $I(x, y)$ gets decomposed into oriented wavelets



- ▶ Technique shifts phase of wavelets in all spatial bands



Phase changes from 0 (Blue) to $\frac{3\pi}{4}$ (Orange)

- ▶ Phase change less than $\frac{\pi}{2}$ has reasonable error
- ▶ Wavelet “wraps around”

Results: Phase-based vs. Linear



Linear (SIGGRAPH'12)

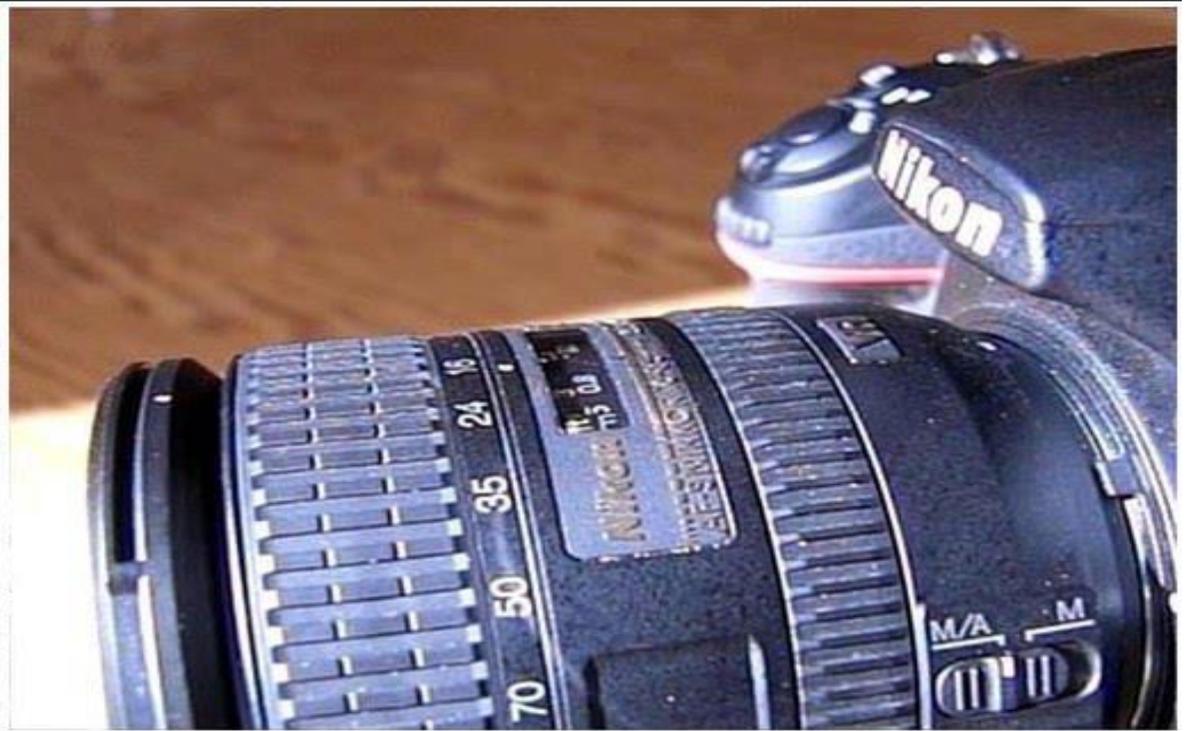
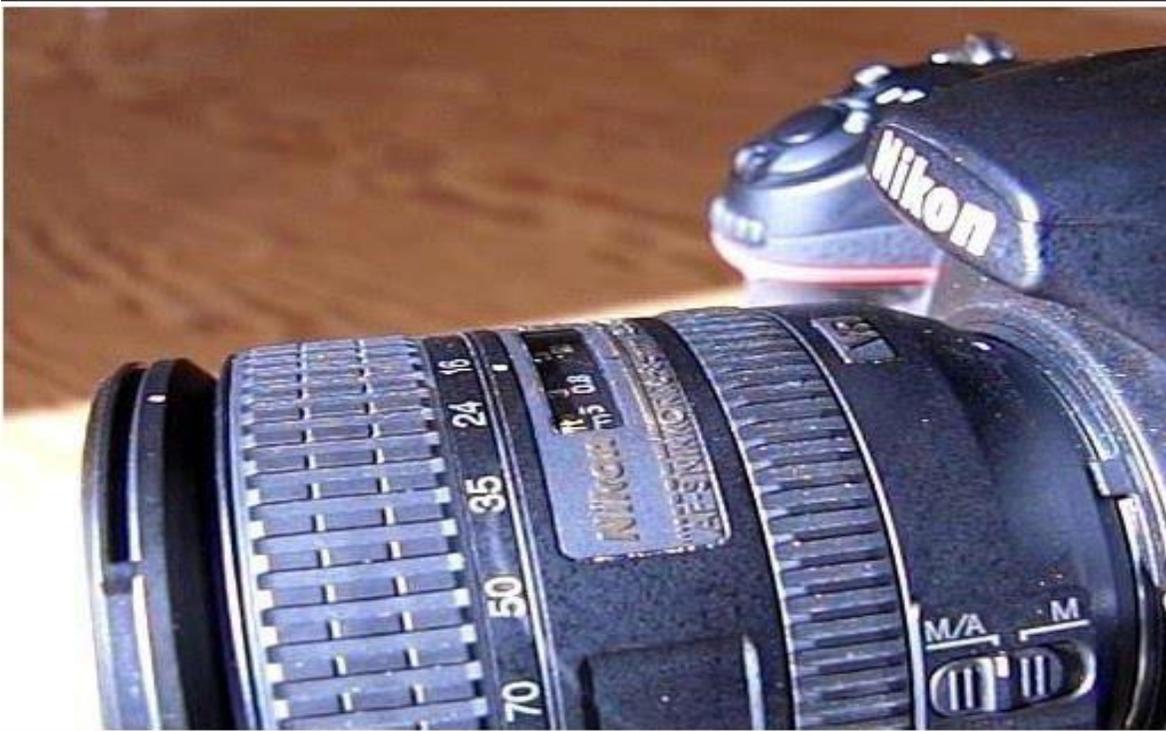


Phase-based (SIGGRAPH'13)

Clipping artifacts near
Sharp edges and larger
motions



Results: Phase-based vs. Linear



Linear (SIGGRAPH'12)

Phase-based (SIGGRAPH'13)



Complex-Valued Eulerian Motion Modulation

Paper ID 0311



Frequency sweep



Frequency sweep



Original

Low Frequencies (0.1 Hz to 0.5 Hz)



Midrange (1 Hz to 2 Hz)

High Frequencies (4 Hz to 16 Hz)



Phase-based Motion Attenuation



Source

Linear

Motion attenuation +
Color amplification

Amplifies color
And motion **jointly**

Amplifies color
**Without amplifying
motion**



Revealing Invisible Changes in the World

- NSF International Science and Engineering Visualization Challenge (SciVis), 2012
- Science Vol. 339 No. 6119 Feb 1 2013



High-speed video, singing single note



Fundamental note, motion magnified x100



1st harmonic motion magnified x100



Non-harmonic frequency, x100



Motion magnification.

Ce Liu, Antonio Torralba, Bill Freeman,
Fredo Durand, and Edward Adelson

**We can register, then amplify,
one motion *relative to* another.**

empty trunk

full trunk



Original footage courtesy of Paul
Robertson, BBN.



Motion magnification.

Ce Liu, Antonio Torralba, Bill Freeman,
Fredo Durand, and Edward Adelson

**We can register, then amplify,
one motion *relative to* another.**

empty trunk

full trunk
(motion difference amplified)



Original footage courtesy of Paul
Robertson, BBN.



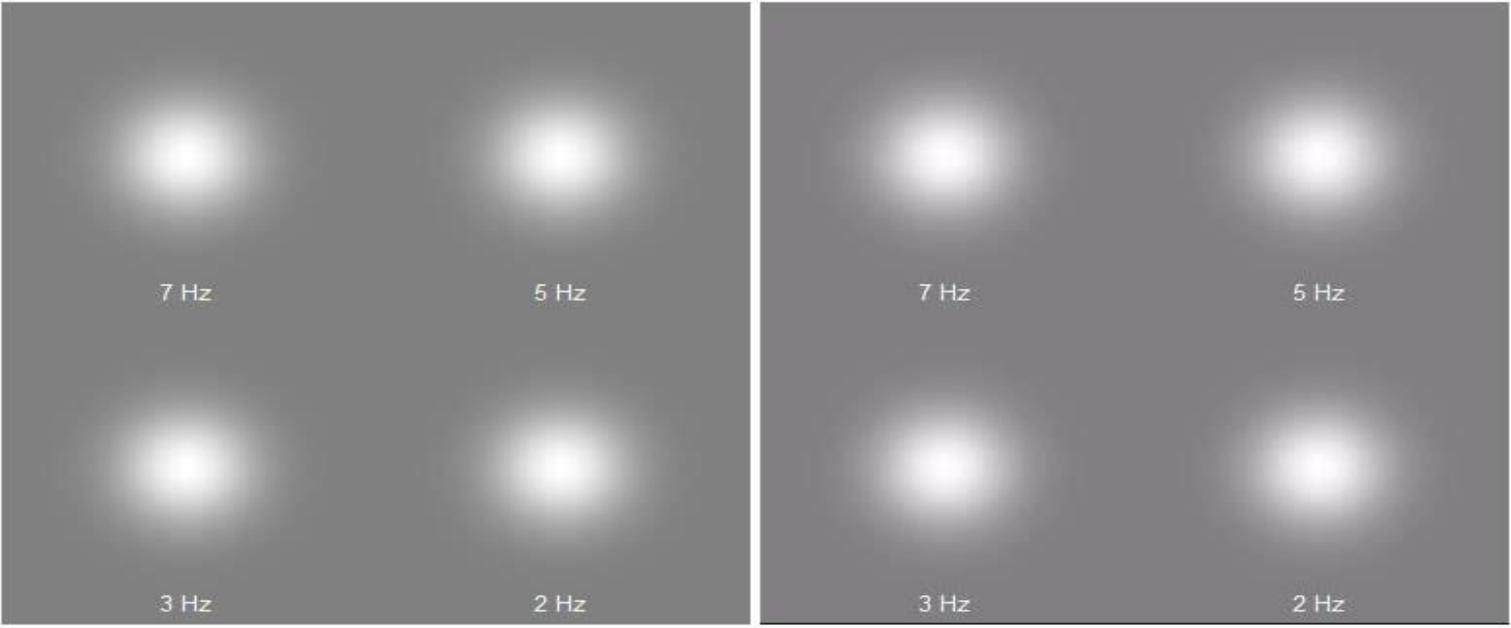
Research project pages: “Eulerian video magnification”
“Phase-based video magnification”

Joint work with Michael Rubinstein, Hao Yu, Eugene Hsu, Neal
Wadhwa, John Guttag, Fredo Durand

Massachusetts Institute of Technology



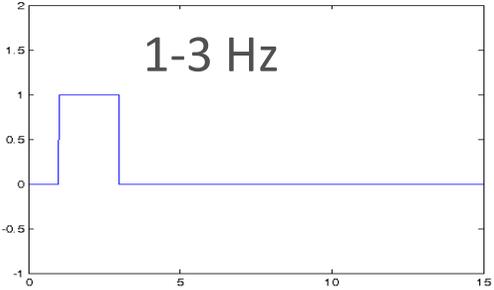
Selective Motion Magnification



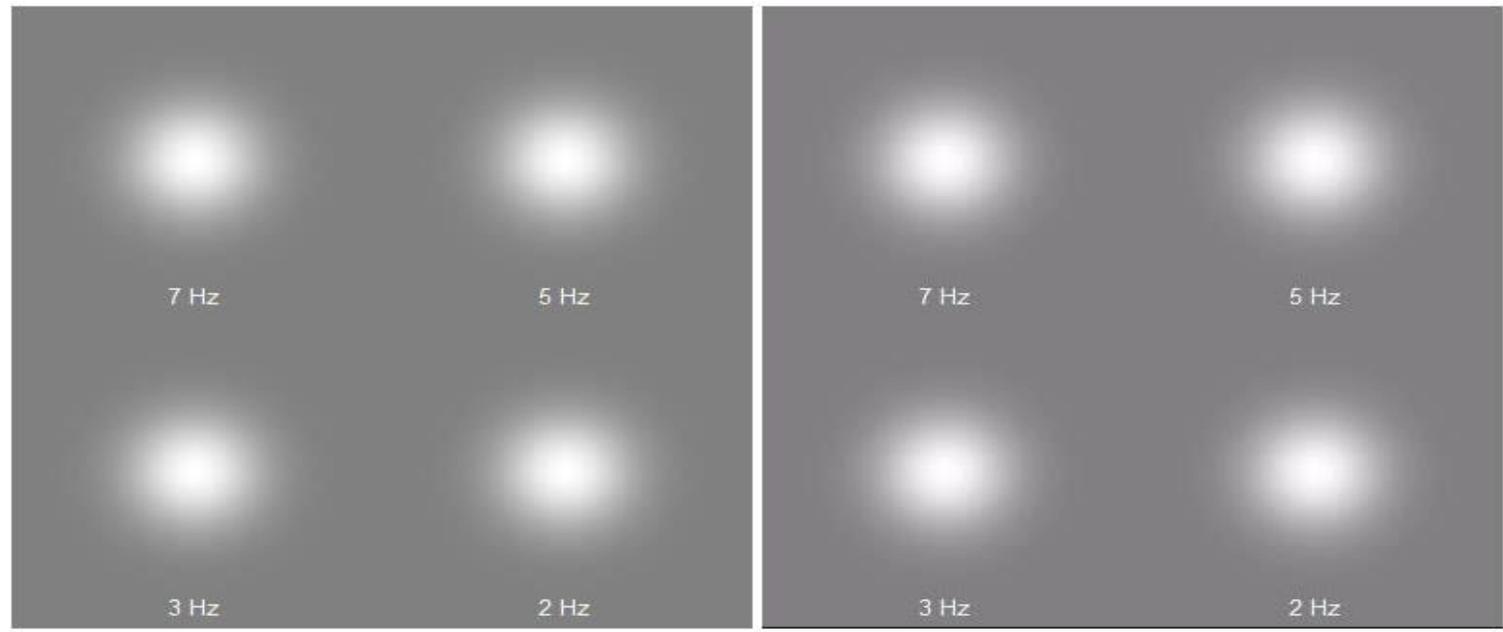
Source

Motion-magnified (2 Hz)

Temporal filter:



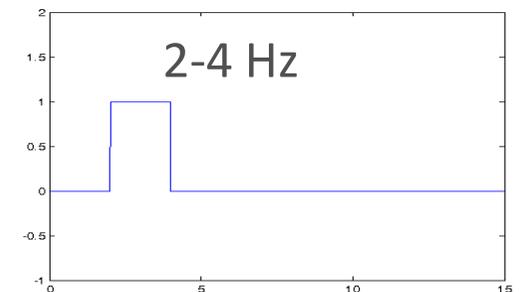
Selective Motion Magnification



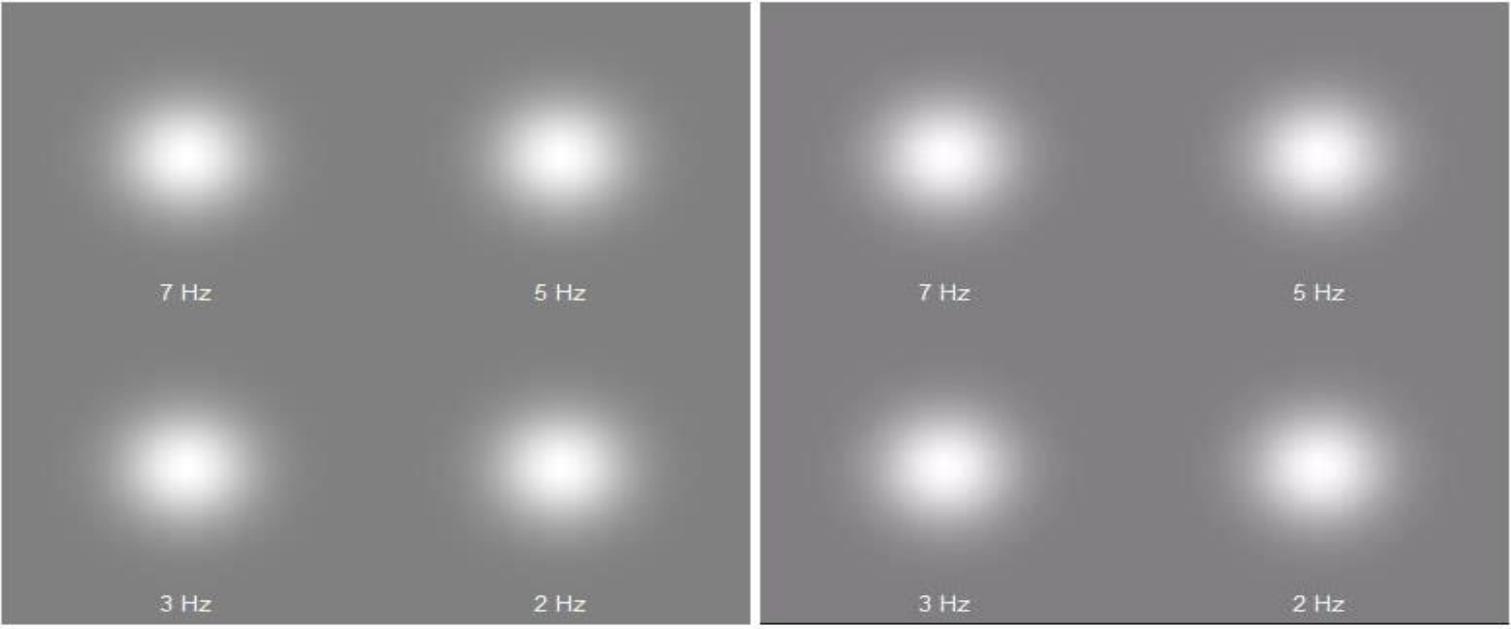
Source

Motion-magnified (3 Hz)

Temporal filter:



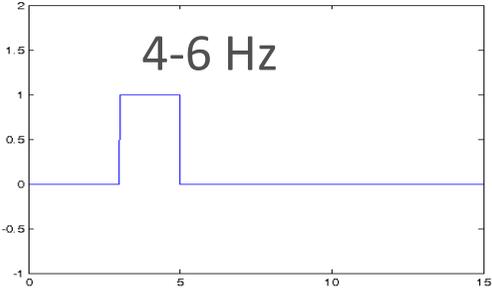
Selective Motion Magnification



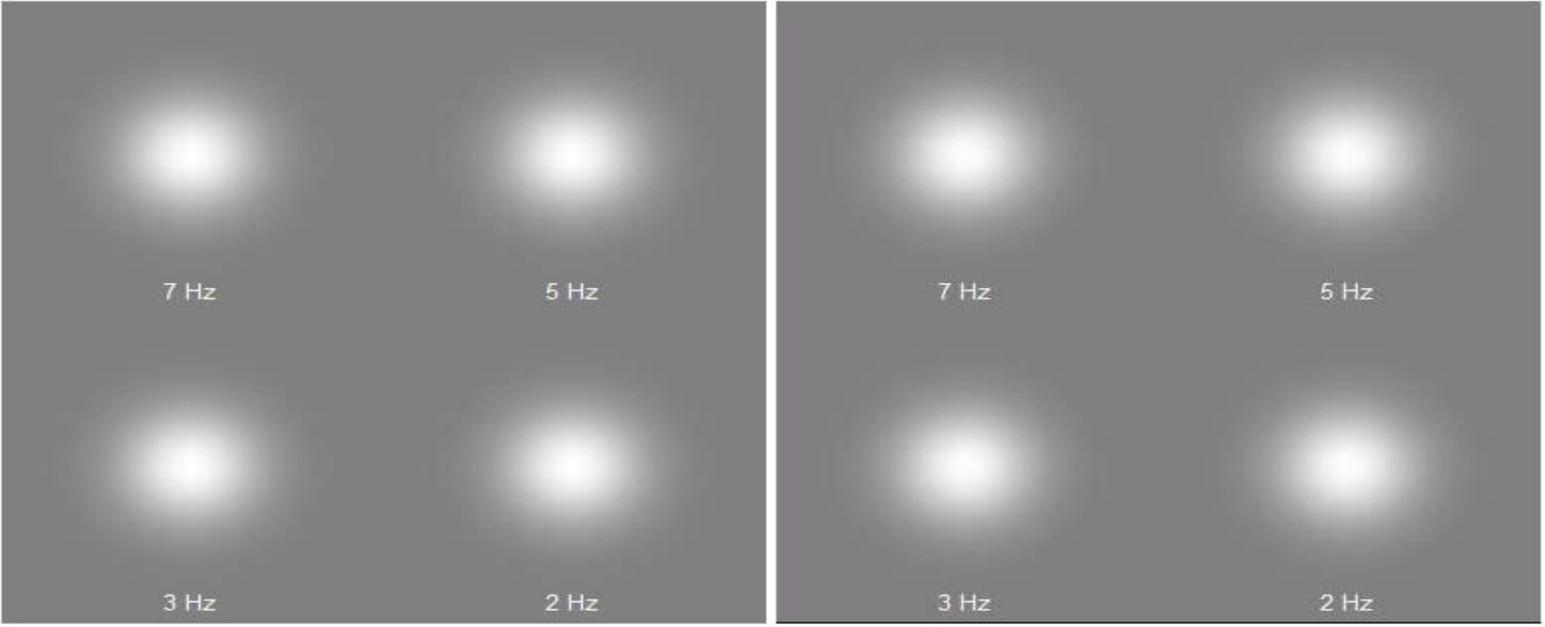
Source

Motion-magnified (5 Hz)

Temporal filter:



Selective Motion Magnification



Source

Motion-magnified (7 Hz)

Temporal filter:

