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.


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

Respiratory motion

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
Amplifying Subtle Color Variations

- 2. Filter Temporally
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

2.33-2.67 Hz (140-160 bpm)

Thanks to Dr. Donna Brezinski and the Winchester Hospital staff
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 $\rightarrow$ RGB averaged over ROI (single number) $\rightarrow$ 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
Motion Magnification via Temporal Filtering

\[ \alpha B(x, t) \]
\[ B(x, t) \]
\[ \sim \delta \]
\[ \sim \alpha \delta \]

Intensity

\[ f(x) \quad f(x + \delta) \quad f(x) + \delta \frac{df(x)}{dx} \quad B(x, t) \quad f(x) + (1 + \alpha) B(x, t) \]

\[ x \ (space) \]
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

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

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

\[ = f(x + \alpha \delta(t)) \]

Modified signal

Assume the amplified translation is still small relative to image structures
Where we expect this to break down
Let’s look at it for f(x) being a sinusoid,

\[
\cos(\omega x + \alpha \omega \delta) = \cos(\omega x) - \alpha \omega \delta \sin(\omega x)
\]

= \cos(\omega x) \cos(\alpha \omega \delta) - \sin(\omega x) \sin(\alpha \omega \delta)

For the motion magnification approximation to hold:

\[
\begin{align*}
\cos(\alpha \omega \delta) &= 1 \\
\sin(\alpha \omega \delta) &= \alpha \omega \delta
\end{align*}
\]

Condition required for those conditions to be approximately true:

\[
\begin{align*}
\sin\left(\frac{\pi}{4}\right) &= 0.9 \frac{\pi}{4} \\
\alpha \omega \delta &< \frac{\pi}{4}
\end{align*}
\]
Synthetic 1D Examples

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

(b) Motion amplification via temporal filtering:
\[
\tilde{I}(x, t) = I(x, t) + \alpha B(x, t).
\]
System Overview

Input video

Spatial Decomposition

Temporal Processing (pixel-wise)

Eulerian video magnification

Reconstruction

Output video
Amplify spatial frequencies where approximation holds, otherwise fail toward zero

**Figure 6:** Amplification factor, $\alpha$, as function of spatial wavelength $\lambda$, for amplifying motion. The amplification factor is fixed to $\alpha$ 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
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:

1-3 Hz
Selective Motion Magnification

Source

Motion-magnified (3 Hz)

Temporal filter:

2-4 Hz
Selective Motion Magnification

Source

Motion-magnified (5 Hz)

Temporal filter:

4-6 Hz
Selective Motion Magnification

Source

Motion-magnified (7 Hz)

Temporal filter:

6-8 Hz
Selective Motion Magnification in Natural Videos

Source (600 fps)

72-92 Hz Amplified

100-120 Hz Amplified

Low E (82.4 Hz)

A (110 Hz)
Motion Magnification Results

Source (300 fps)  Motion-magnified (45-100 Hz, x100)
DSLRL Controlled Setup

- Laser pointer
- Reflected laser point
- Source (300 fps)
- Motion-magnified (45-100 Hz, x100)
- Standard A4 sheet
- Same DSLR camera (Nikon D400)
Eulerian vs. Lagrangian Motion Magnification

- 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)

wind.mov  lens1.mov  lens1.mov  candle.mov
Independent (Real-time) Ports

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

“V Amp - Video Amplifier”
(Java)
EVM in the Wild: Pregnancy

“Tomez85”
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!

“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 $\omega$ and orientation $\theta$
- Transfer functions partition frequency domain
- Apply filters $T_{\omega,\theta}$ to image $I(x, y)$ by doing

$$S_{\omega,\theta} = \mathcal{F}^{-1}\left\{ T_{\omega,\theta} \times \mathcal{F}\{I\} \right\}$$

To Primal Basis
Isolate components
To Fourier Basis

\[\begin{align*}
\theta &= 0, \quad \omega = 100 \\
\theta &= \frac{\pi}{2}, \quad \omega = 100 \\
\theta &= 0, \quad \omega = 50
\end{align*}\]

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

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
Phase-based Motion Attenuation

Source

Linear

Amplifies color
And motion *jointly*

Motion attenuation +
Color amplification

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
1\textsuperscript{st} harmonic motion magnified x100
Non-harmonic frequency, x100
We can register, then amplify, one motion *relative to* another.

Original footage courtesy of Paul Robertson, BBN.
We can register, then amplify, one motion *relative to* another.

Original footage courtesy of Paul Robertson, BBN.
Research project pages: “Eulerian video magnification”
“Phase-based video magnification”

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

Massachusetts Institute of Technology
Selective Motion Magnification

Source

Motion-magnified (2 Hz)

Temporal filter:

1-3 Hz
Selective Motion Magnification

Source

Motion-magnified (3 Hz)

Temporal filter:

2-4 Hz
Selective Motion Magnification

Source

Motion-magnified (5 Hz)

Temporal filter: 4-6 Hz
Selective Motion Magnification

Source

Motion-magnified (7 Hz)

Temporal filter:

6-8 Hz