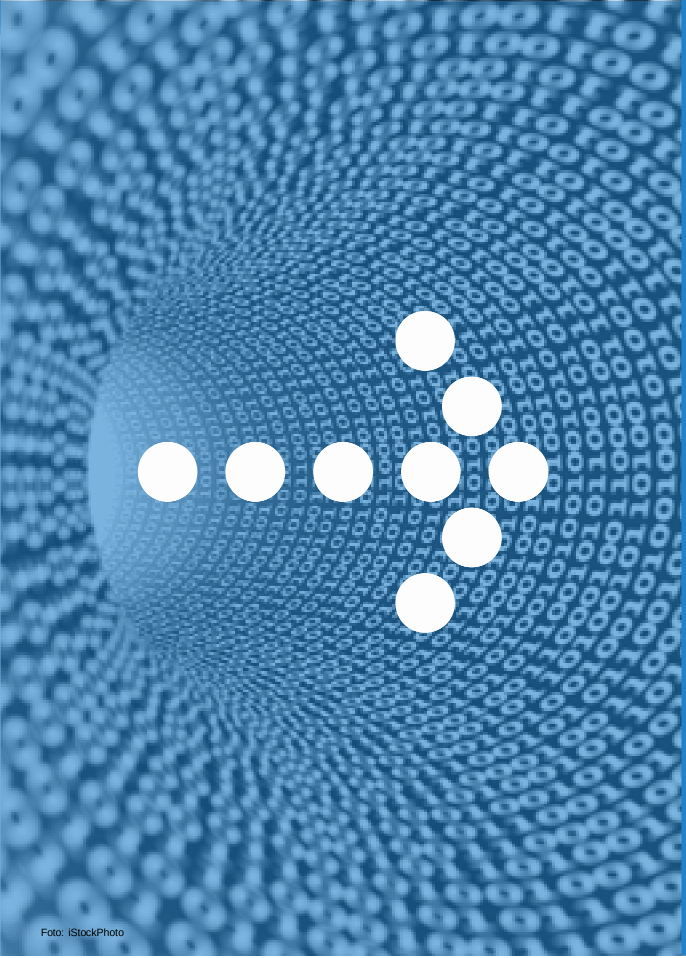


Foto: iStockPhoto

Detection and localization of light flashes using a single pixel camera in SWIR

Carl Brännlund, Andreas Brorsson, David Bergström, David Gustafsson, Martin Oja & Sebastian Olsson

Swedish Defence Research Agency (FOI), 2019

Outline

- Goal
- Background (Muzzle flash)
- Single Pixel Camera
- System design
- Signal processing
- Measurement & Results
- Conclusions
- Future improvements
- Questions

Goal

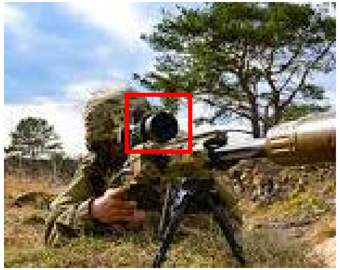
Counter snipers with a Single Pixel Camera

- Detection & localization gun Muzzle Flashes
- Discriminate false alarms

… while capturing images

With a laser:

- Detect reflections in Sniper Optics (pre-shot)



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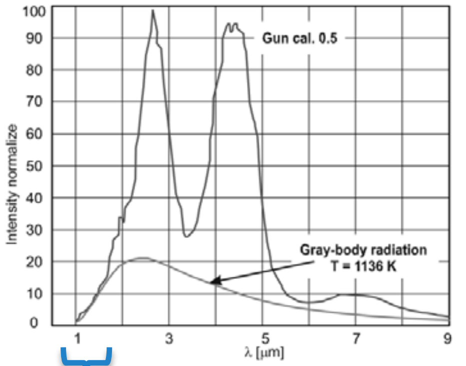
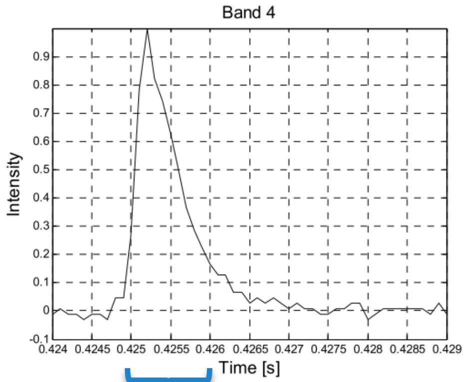
Muzzle flash

- Optical weapon signature
- Short events (~1 ms)
- **VIS** - Visual spectrum
  - Hard to detect (especially in daylight)
- **MWIR** (3-5 µm)
  - Highest MF signature
  - Expensive
  - Outside DMD glass transmission
- **SWIR** (0.8-1.7µm)
  - Used in our design



SWIR

Spectral curve



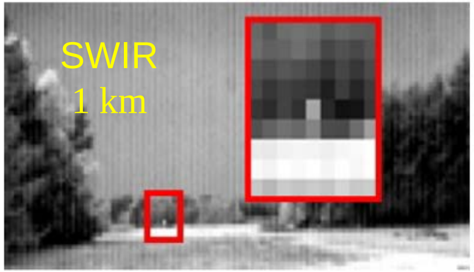
1 ms

Temporal signature
(2.13 - 2.57 µm)

Standard detection & localisation method

High speed infrared camera (~1000 Hz)

- High cost (many units needed)
- MF visible in 1 pixel in 1 frame
- Many frames needs to be analysed
- Lots of data
- High computing power needed



When a flash is detected:

- Not fast enough to resolve the MF with multiple samples
- False alarms is a problem (such as sun reflections)

World's fastest InGaAs camera (SWIR)
Cheetah-640-CL **1700 Hz**
http://www.xenics.com

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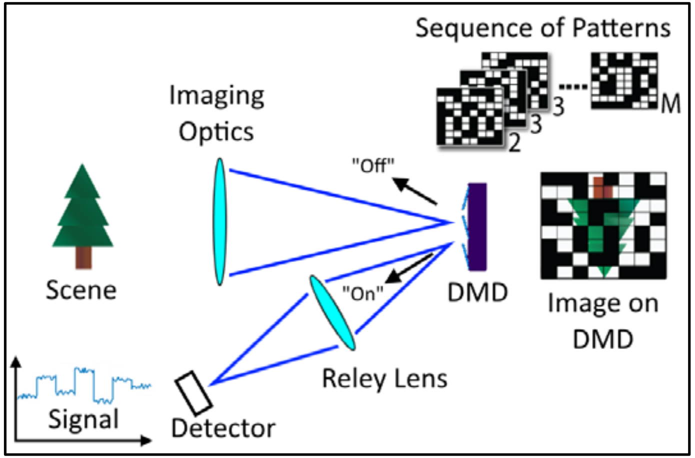
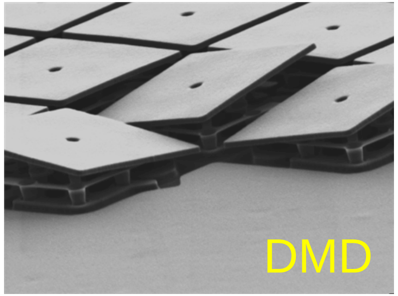
Single Pixel Camera (SPC)

- Scene focused on Digital Micromirror Device (DMD)
- Random patterns are displayed on the DMD
- 1 value extracted per pattern
- An image is restored using an algorithm.
- Less measurements than pixels is needed (sub-Nyquist). Possible because natural images are sparse in some basis.
- Low cost
- Only one detector needed
- Easy to change wavelength
- Main drawback – Slow (How to detect 1ms events?)





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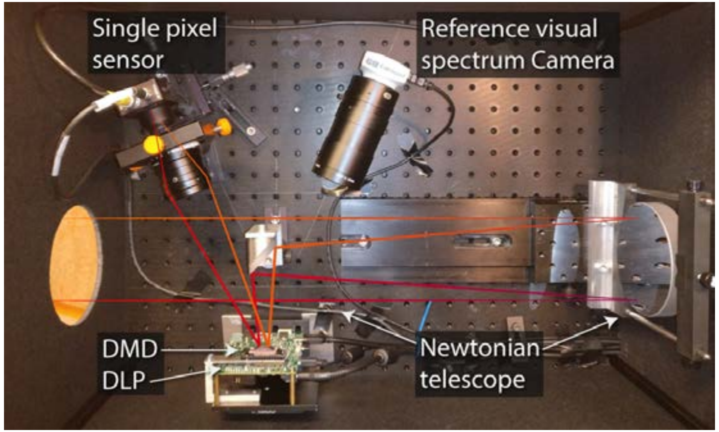
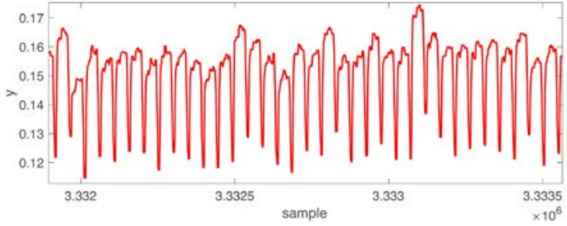
System design

- InGaAs detector (800-1700nm)
- DLP® LightCrafter™ 4500, DLP4500NIR
  - max 4000 Hz
  - Low cost (faster units available)
- Newtonian Telescope (mirrors have a very wide reflection band)
- Visual reference camera



Measured signal



Complete system design: Compressed Imaging at Long Range in SWIR, Brorsson, A., Brannlund, C., Bergstrom, D., and Gustafsson, D.
To appear in: Scandinavian Conference on Image Analysis (SCIA) (2019)

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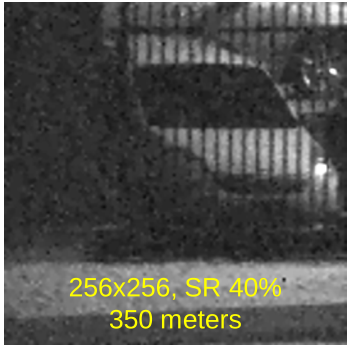
Reconstruction algorithm & measurement matrix

Reconstruction algorithm

- TVAL3
- Total Variation (TV) algorithm
- Considers the gradient of the signal being sparse
- Fast
- Available online

Random measurement matrix

- Scrambled sequency ordered Walsh Hadamard matrix
- Faster reconstruction
- Not necessary to store the whole matrix in memory



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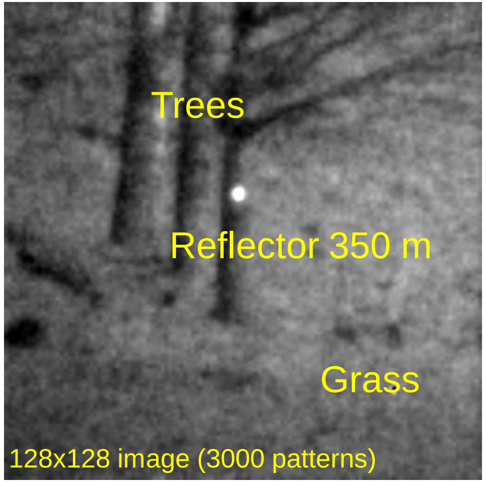
Muzzle Flash Experiment

- Bright outdoor scene
- DMD resolution 32x32 (binned micromirrors)
- MF simulated with a laser irradiating a reflector

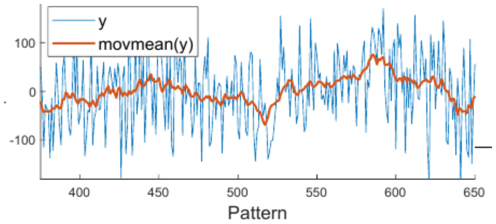
- Pattern rate 1440 Hz (to slow to locate a 1ms MF)
  - Slow 25 ms square pulse (36 patterns per pulse)
  - 36 patterns would translate to a 1.1 ms MF if a high speed DLP unit is used (with a 32 kHz sampling rate).

- This measurement can also be considered as detection of sniper optics with a laser
  (signature of reflector vs sniper optics??? Not measured.)



In this measurement the laser was continuously on

Signal with Muzzle Flash



Laser parameters: 7W, 20mrad, 1550nm

Background reduction

- SPC is slow, many samples needed to create an image.
- How to restore images of fast events?
  - Possible if the scene is very sparse
  - Our scene is not sparse enough
  - The MF is very sparse

➡ Remove Background!

- Measuring the same scene twice (close in time)
  - Raw signal
- Before image restoration
  - Subtracting the scene information
  - Leaving (small?) changes between measurements

➡ Only Muzzle Flash remains

$y_{reduced} = y_{pulse} - y_{background}$

y_{pulse} - signal with the muzzle flash

$y_{background}$ - signal pre or post the muzzle flash

Same patterns in y_{pulse} and $y_{background}$

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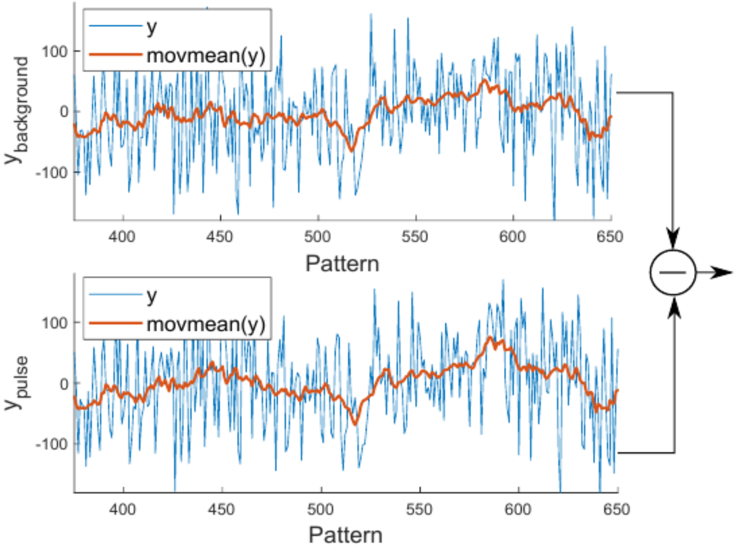
Background reduction – Real measurement

2 Signals with
scene data

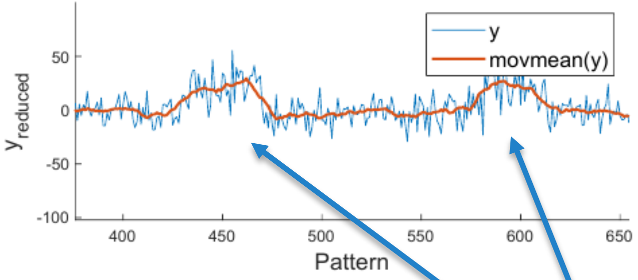
Signal pre or
post MF

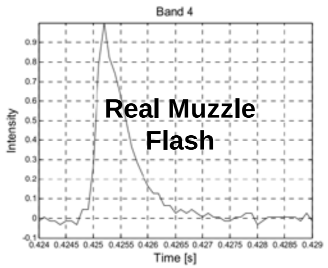
Muzzle Flash
signal



In this data 1 min between measurements

Scene data
removed



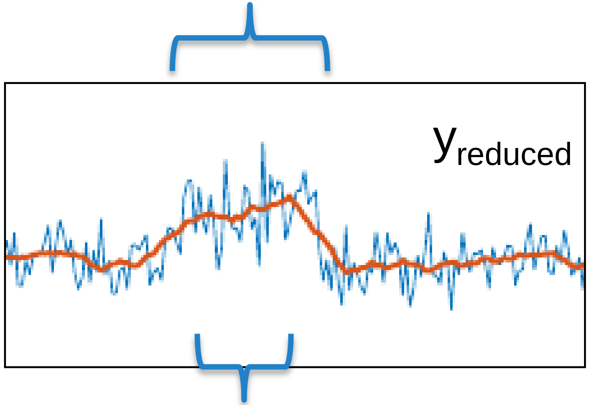


MF?

Compare length &
temporal signature

Image of the simulated Muzzle Flash

36 patterns (length of MF)



20 samples is restored using TVAL3 (1 iteration)…

M=20

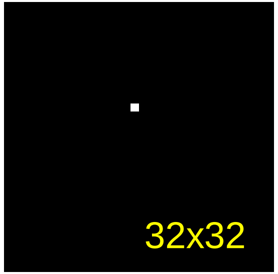
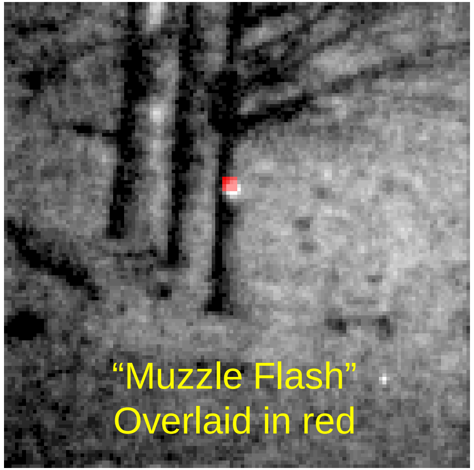


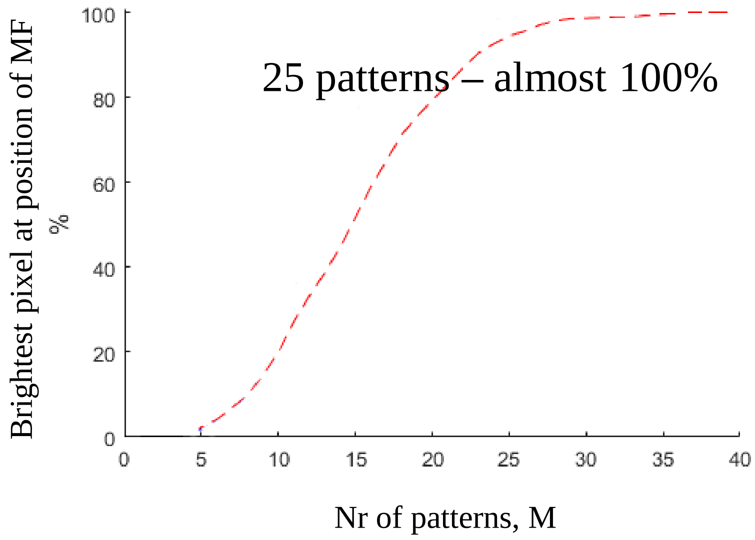
Image with one dominatic pixel (thresholded)

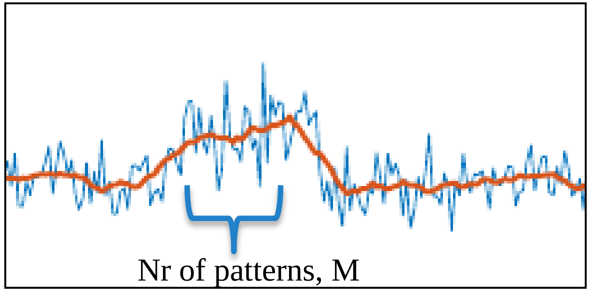


…more samples better result
…more iterations isn't necessary better (with so few samples)

Number of samples needed to locate the MF?

- Multiple measurements (many different patterns and MF-lengths)
- Simulated with one very long MF (CW)
- Background reduce
- Restore images
  …with different length
  …different individual patterns
  …using 1 iteration in TVAL3
- The brightest pixel is considered as the position of the MF





Conclusions

- Detection & localisation of shorter than 25ms events at 1440Hz.
- A 99% localization probability is provided after 25-30 samples, at 32x32 resolution.
- Discrimination can be performed by analysis of the temporal signal
- Sniper optics detection may be possible with a laser.

Future experiments

- Real Muzzle Flash
- Real sniper sight
- Test higher resolutions than 32x32

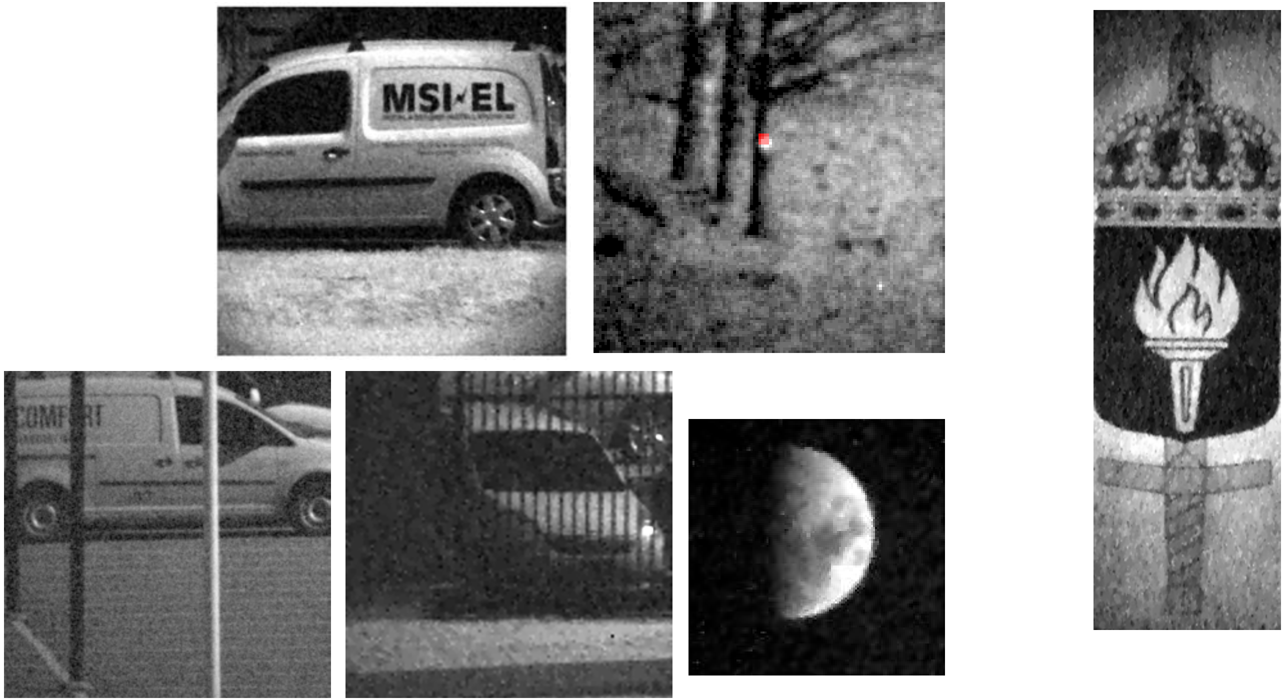
Future system improvements

System design

- New High speed DMD-unit (32kHz?)
  - 4000 Hz is not fast enough to locate a MF)
- Wider FOV (Important for a real system)
- Double detectors
  - Measure 100% of the light
  - Better SNR
  - Multiple wavelength bands
- A more suitable algorithm than TVAL3?
- Better measurement matrix?

Thank you!

- Questions?



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ABSTRACT

- ***Long range single pixel camera (SPC)***
- ***Short-wave infrared (SWIR)***
- ***Detect and localize fast events***
- ***Gun Muzzle flash***

A high-resolution single pixel camera for long range imaging in the short-wave infrared (SWIR) has been evaluated for the detection and localization of transient light flashes. The single pixel camera is based on an InGaAs photodiode and a Newtonian telescope, with a digital micromirror device (DMD) operating as a coded aperture. Images are reconstructed using compressed sensing theory, with Walsh-Hadamard pseudo-random measurement matrices and a total variation based regularization method (TVAL3). Results from experiments with light flashes are presented and the potential use of the camera for muzzle flash detection and localization is discussed.

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