



Moving Shadow Detection by Nonlinear Tone-Mapping

Elad Bulkich SIPL - Dept. of EE - Technion

Idan Ilan SIPL - Dept. of EE - Technion

Yair Moshe SIPL - Dept. of EE - Technion

Dr. Hagit Hel-Or Dept. of CS - University of Haifa

Prof. Yacov Hel-Or Google Inc.



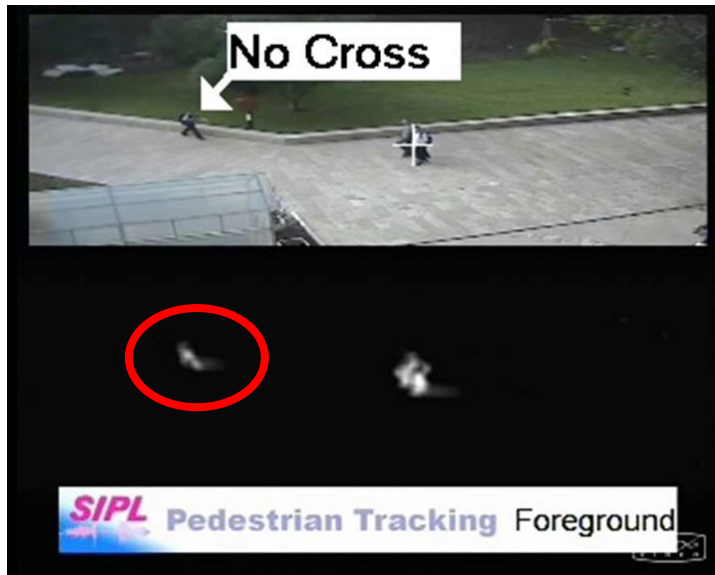
Presentation's Outline

- Introducing the problem
- Existing Solutions
- Proposed Solution
- Metric Approximation
- Results
- Conclusion

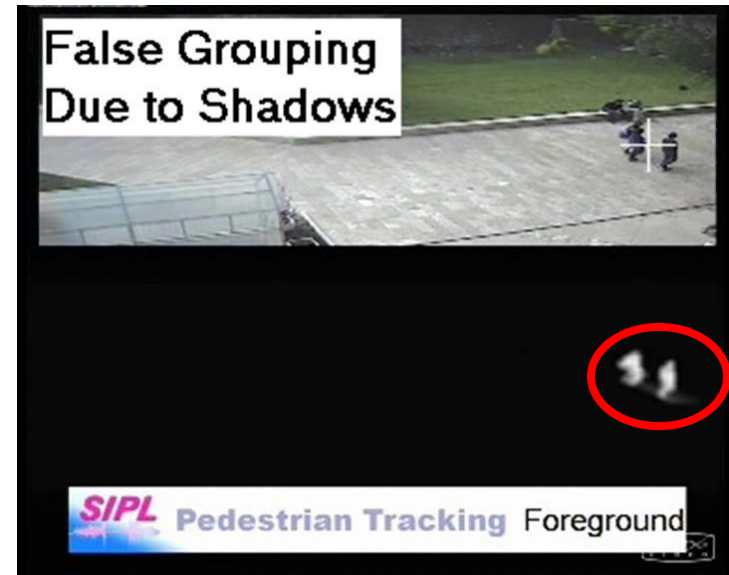
Introducing the Problem

- Surveillance systems perform object segmentation & tracking
- Moving shadows may cause identification failure

No Detection



Object Merging



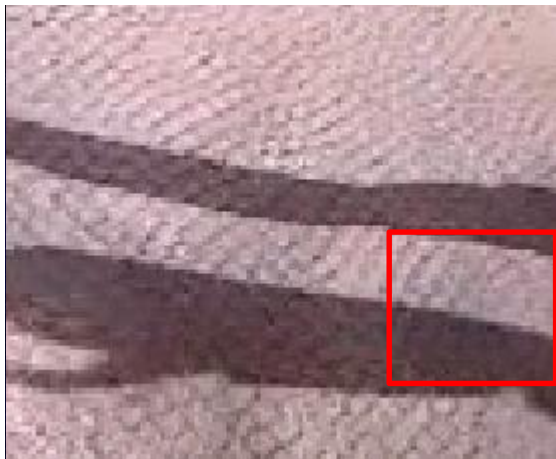
Existing Solutions

- Most solutions are not suitable for shadow detection using a **low-cost outdoor surveillance camera**
 - Solutions are designed for specific conditions
 - May require pre-calibration of camera and scene parameters
 - May use assumptions that are not met in a surveillance scenario
 - Difficult to generalize

Proposed Solution

- **Assumption:** Structural content (textures and edges) is preserved from the original non-shadowed scene in shadowed regions

Shadowed



Background



Proposed Solution

- **Observation:** Non-linear tone mapping between background and shadow



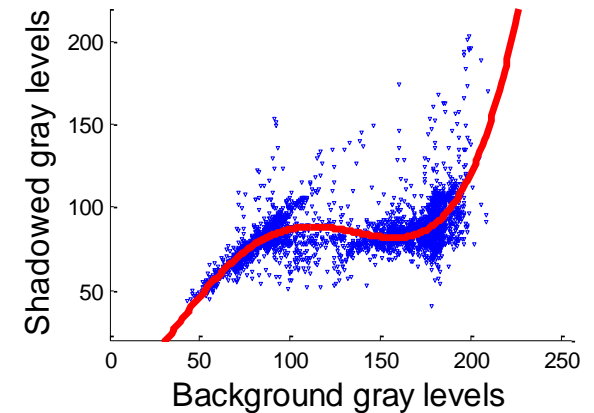
(a)

Background



(b)

Shadowed



(c)

Tone mapping

Shadow Detection Scheme

- Use a non-linear tone-mapping-invariant metric termed **Matching by Tone Mapping (MTM)**
 - Recently proposed by (Hel-Or et al., ICCV 2011)
- Measure MTM between suspected foreground p and background w pixels:

$$D(p, w) = \min_{\mathcal{M}} \left\{ \frac{\|\mathcal{M}(p) - w\|^2}{m \cdot \text{var}(w)} \right\}$$

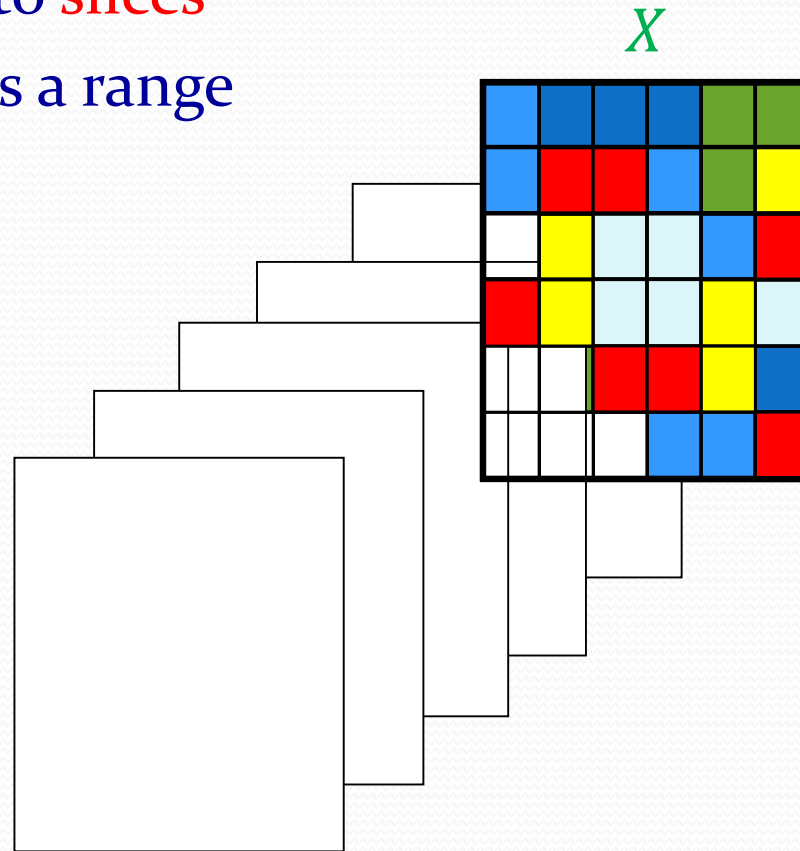
Non-linear mapping

Denominator enforcing scale invariance

- Can be approximated very efficiently
- Compensates for non-linear mapping
 - Small value \Rightarrow shadow
 - Large value \Rightarrow foreground

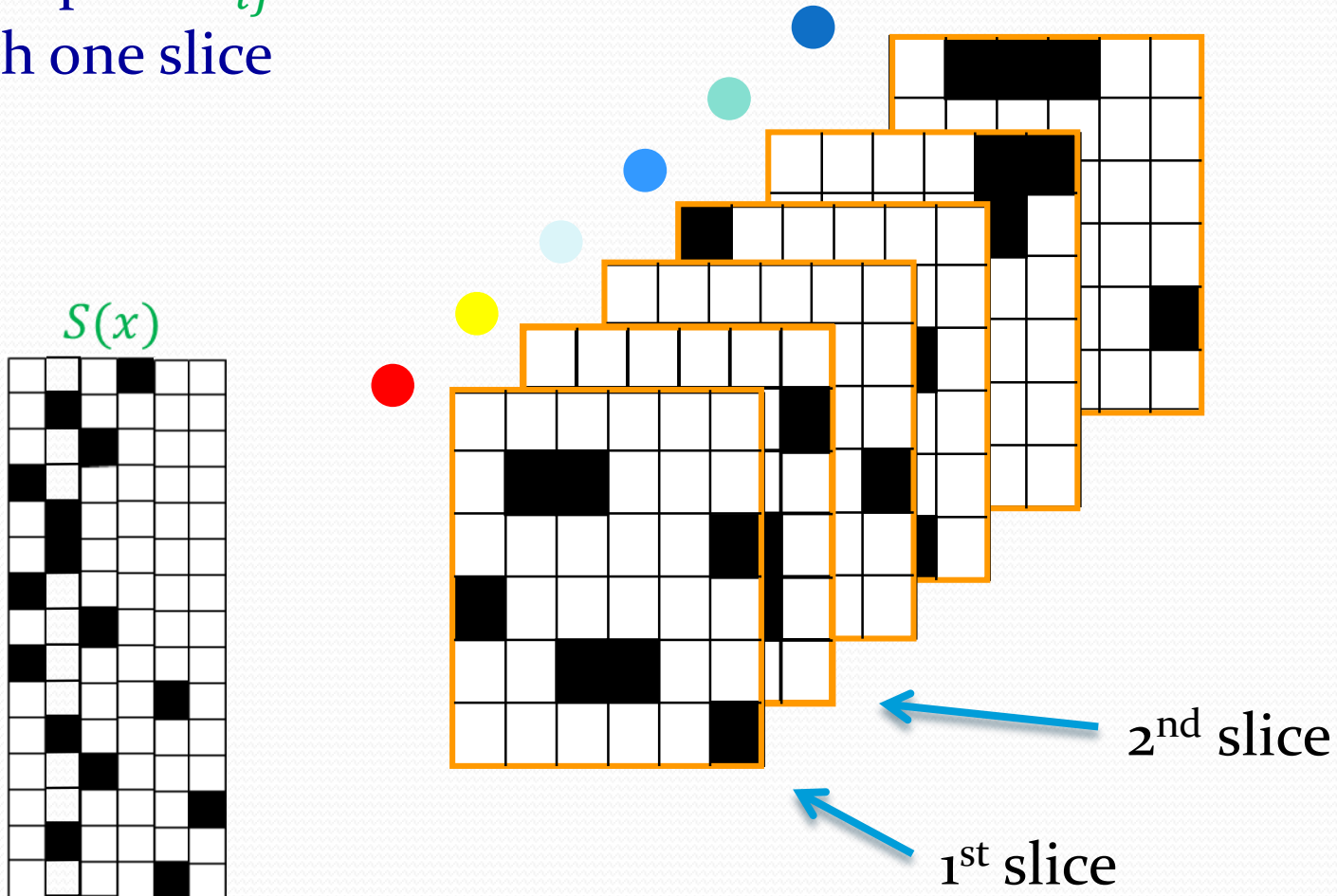
Metric Approximation

- Divide the image into **slices**
- Each slice represents a range of gray levels



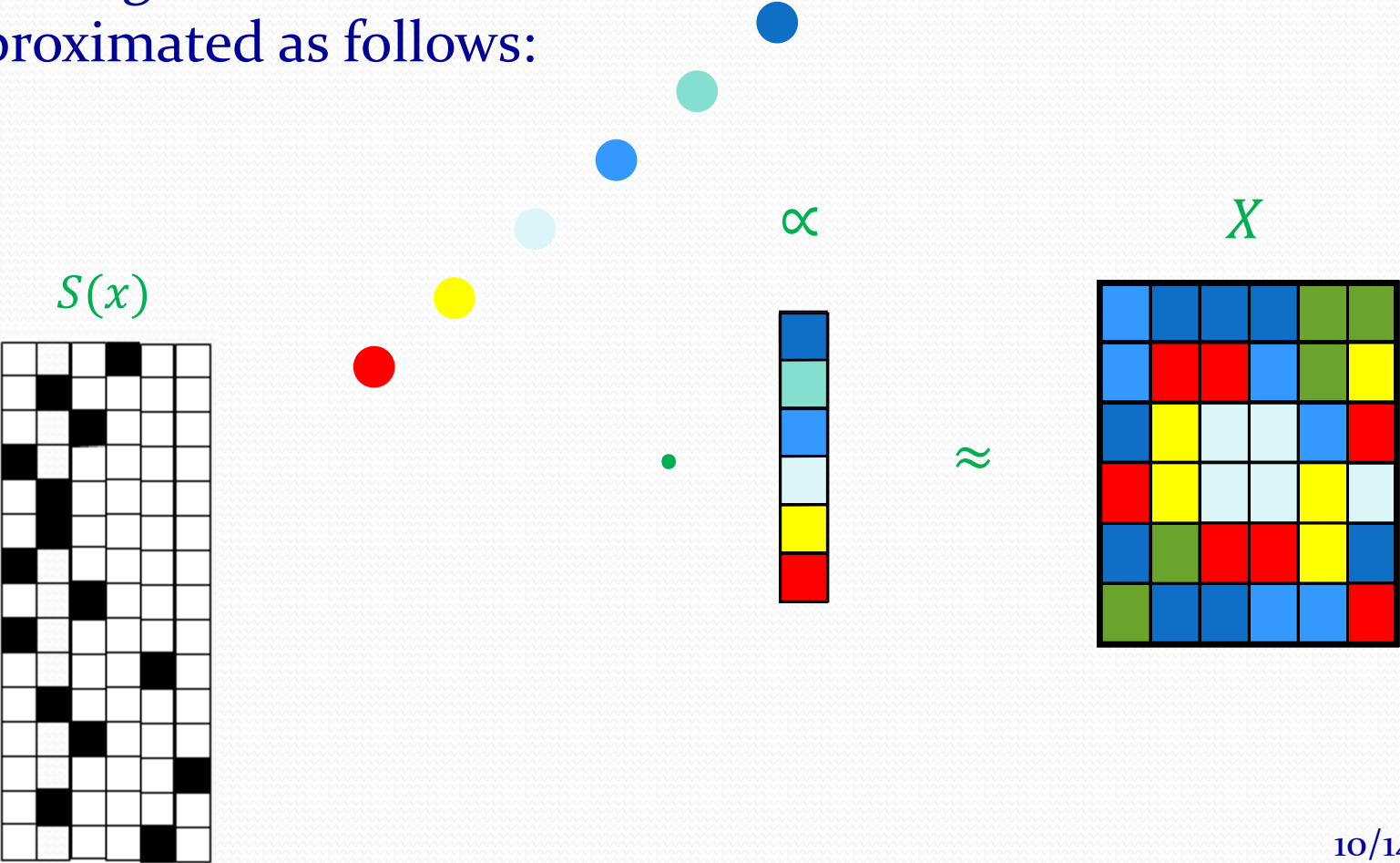
Metric Approximation

- Each pixel X_{ij} is associated with one slice



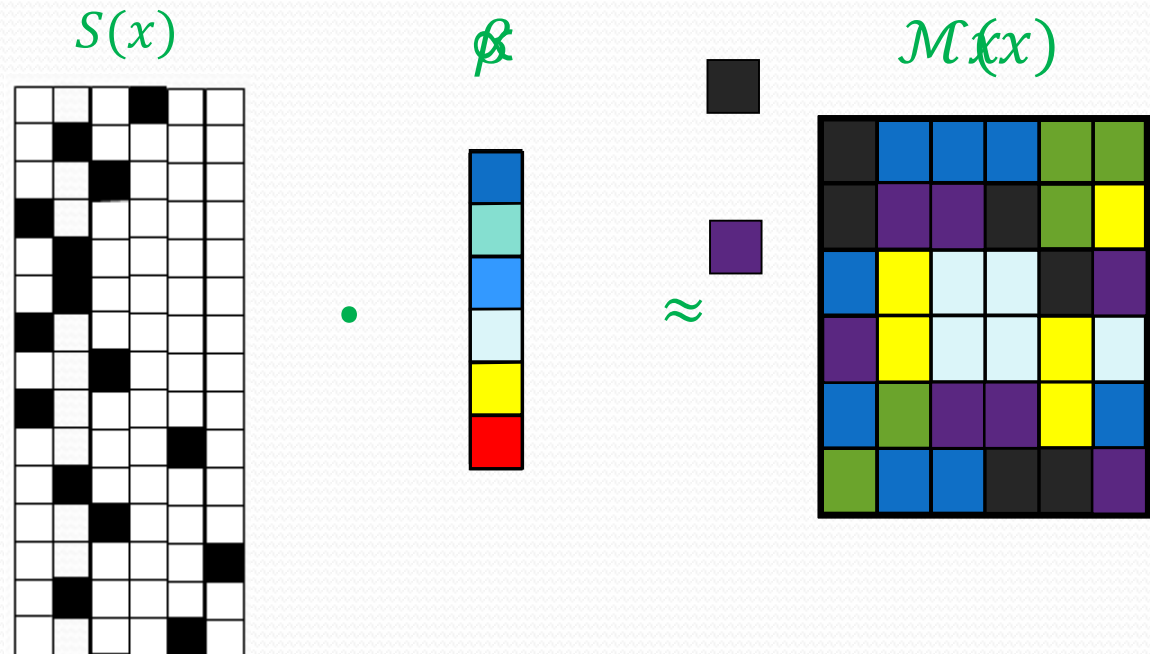
Metric Approximation

- The image X can be approximated as follows:



Metric Approximation

- And in the same way we can represent any piece-wise constant mapping of the image

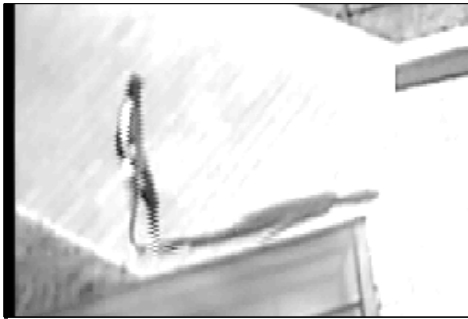


Metric Approximation

- “Raw” MTM metric: $D(p, w) = \min_{\beta} \left\{ \frac{\|M(p) - w\|^2}{m \cdot \text{var}(w)} \right\}$
- Giving $M(p) \approx S(p)\beta$, the solution for this minimization problem is: $\hat{\beta} = \underset{\beta}{\text{argmin}} \|S\beta - w\|^2 = (S^T S)^{-1} S^T w$
- Finally, we get:

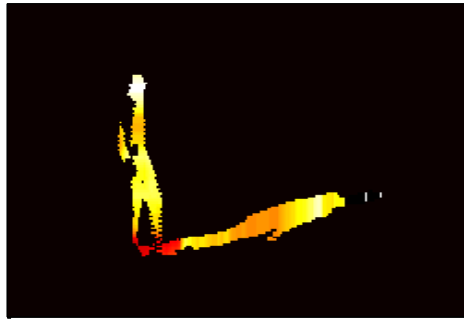
$$D(p, w) = \frac{1}{m \cdot \text{var}(w)} \left[\|w\|^2 - \sum_j \frac{1}{|p^j|} (p^j \cdot w)^2 \right]$$

Distance Map



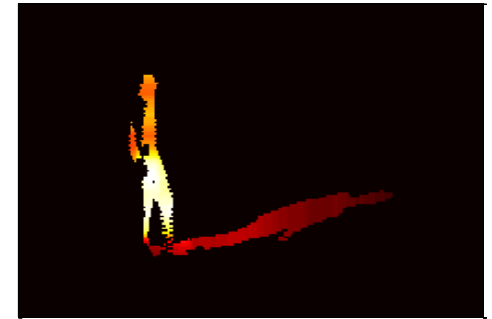
(a)

Original



(b)

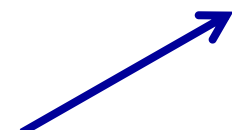
Distance maps using
Normalized Cross
Correlation (linear
tone mapping)



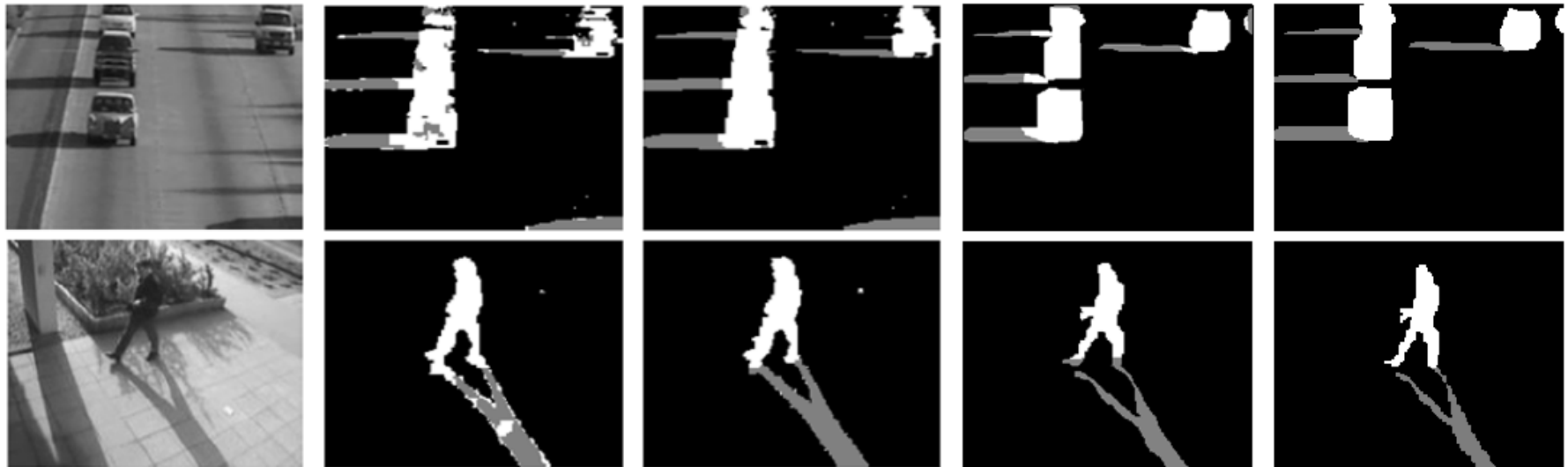
(c)

Distance maps using
proposed technique

Clear separation
between foreground
and shadow



Results



(a)

(b)

(c)

(d)

(e)

Original

CR - Constant ratio (Stander et al., 1999)

SS - Statistical shadow (Benedek & Sziranyi, 2011)

Proposed

Ground truth

Images are taken from “SZTAKI Benchmark Set for Foreground and Shadow Detection in Video Sequences”. (<http://cvrr.ucsd.edu/aton/shadow/>)

Results

- Better than state of the art

Sequence	Precision			Recall			F-measure		
	CR	SS	MTM -PWC	CR	SS	MTM -PWC	CR	SS	MTM -PWC
Highway	0.644	0.805	0.925	0.866	0.890	0.914	0.746	0.845	0.920
Seam	0.596	0.774	0.971	0.946	0.968	0.947	0.731	0.861	0.959
Senoon	0.742	0.833	0.935	0.980	0.963	0.953	0.845	0.894	0.944
Sepm	0.621	0.830	0.908	0.972	0.961	0.914	0.756	0.891	0.911

Conclusion

- A novel moving shadow detection technique
- Based on nonlinear tone mapping between shadows and background
- Uses the **Matching by Tone Mapping (MTM)** approach for efficiently comparing patches
- ✓ Low computational complexity
- ✓ Robust
- ✓ Substantially outperforms state-of-the-art shadow detection techniques in typical surveillance scenarios