RUTGERS

Photometric Modeling for Active Scenes

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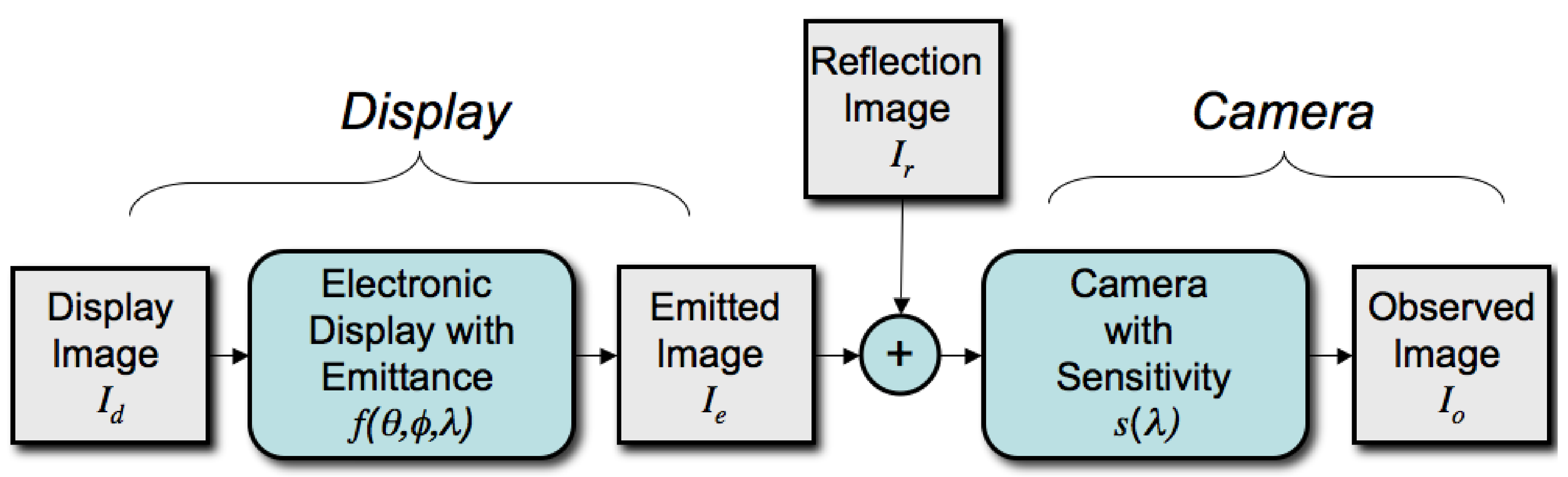
Abstract

The prevalence of electronic displays provides opportunities to develop computer vision methods for active scenes where intentional information is placed and must be recovered. These active scenes are fundamentally different from traditional passive scenes because image formation is not based on object reflectance. In this paper, we develop a model for image formation of an active scene containing electronic displays. We employ this model to embed and recover information within a displayed image. The message is hidden and dynamic. This method is called photographic steganography since the message is hidden and a handheld camera pointed at the display can receive not only the display image, but also the underlying message. Unlike standard watermarking and steganography that lie outside the domain of computer vision, our message recovery algorithm uses color and reflectance modeling to achieve high accuracy of message recovery in real world scenes.



Photometric Model

- *3 components of the display image* I_d: (ρ_r, ρ_g, ρ_b)
- *The monitor emittance function* $f(\lambda,\theta)$ *is a function of wavelength* λ *and viewing angle* $\theta = (\theta_v, \varphi_v)$
- *The emitted light* I_e

$$I_e(x,y,\lambda) = \rho_r f_r(\lambda,\theta) + \rho_g f_g(\lambda,\theta) + \rho_b f_b(\lambda,\theta)$$

$$I_e(x,y,\lambda) = \rho \cdot f(\lambda,\theta)$$

- *Camera sensitivity function* $s(\lambda) = (s_r(\lambda), s_g(\lambda), s_b(\lambda))$
- *3 components of the observed image* $I_o = (I_o^r, I_o^g, I_o^b)$
- Observed image: $I_o \propto \int_\lambda [\rho \cdot f(\lambda,\theta)] s(\lambda) d\lambda$

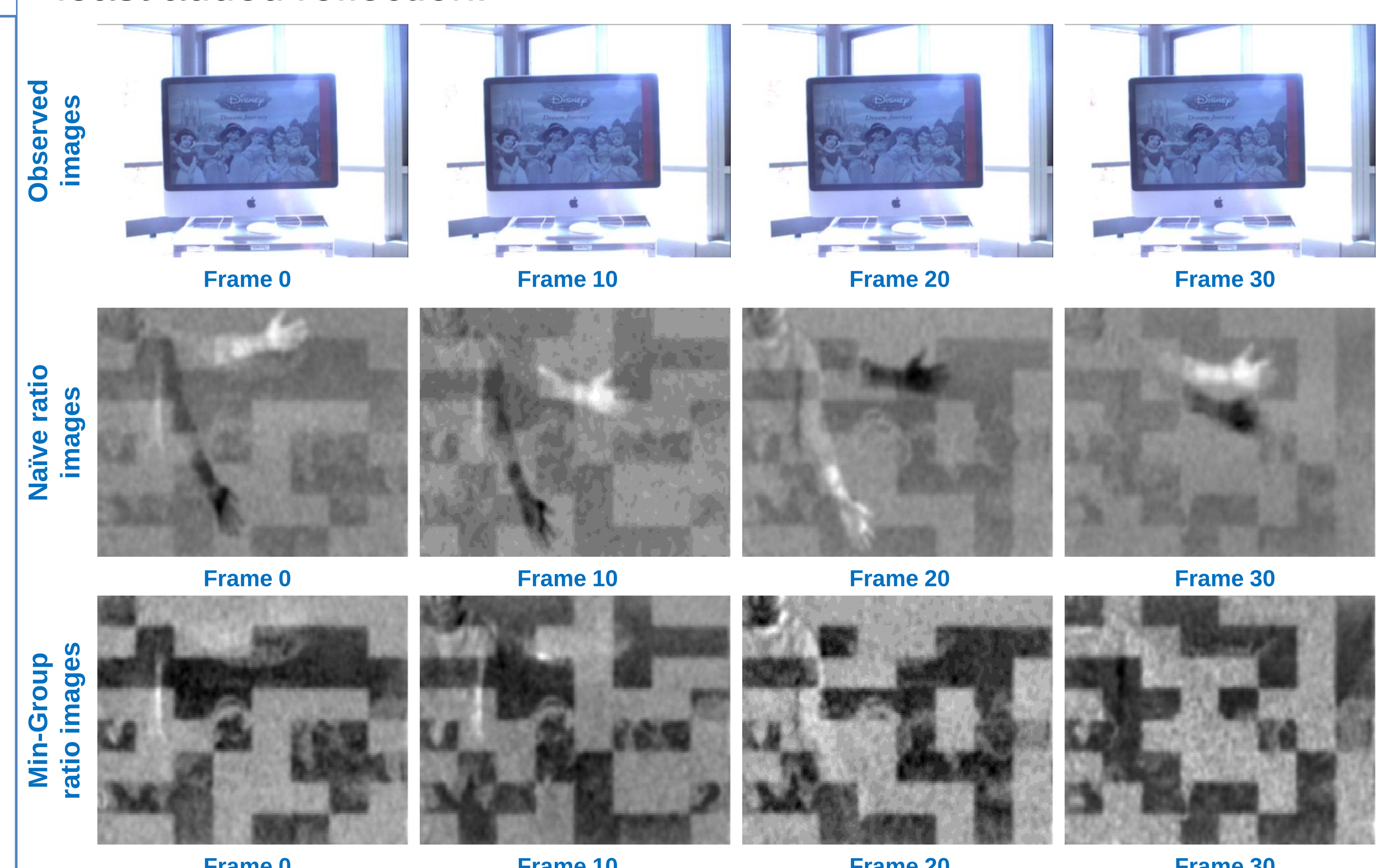
Embedding and Recovering Information

- *Modulated image* $I_1 \propto \int_\lambda [\kappa\rho \cdot f(\lambda,\theta)] s(\lambda) d\lambda$
- *Unmodulated image* $I_2 \propto \int_\lambda [\rho \cdot f(\lambda,\theta)] s(\lambda) d\lambda$
- *Extract ratio image* $\frac{I_1}{I_2} = \kappa$
- *The desirable property of photometric invariance*

(a) Original (b) A message image (c) Embedded without pyramid (d) Embedded with pyramid

Reflection Removal

We use the minimum operation for the neighboring N repetitive frames to weaken the dynamic reflection. This method is called as the *min-group ratio*. Specifically, the message is embedded in N frames and for each pixel, the minimum intensity over the N frames is computed and stored. The same frame repetition holds for the image without the embedded message. Since the reflection component adds to the overall intensity, finding the minimum of the series corresponds to finding the pixel with the least added reflection.



Experiments

- *Average accuracy of the indoor case*

Camera	Naïve Ratio	Min-Group Ratio	Naïve Additive	Min-Group Additive
Static	97.0%	**97.6%**	93.3%	96.4%
Moving	93.1%	**94.9%**	76.9%	83.2%

- *Average accuracy of the outdoor case*

Camera/ Reflection	Naïve Ratio	Min-Group Ratio	Naïve Additive	Min-Group Additive
SCSR	95.2%	**96.6%**	90.6%	95.3%
SCDR	85.3%	**94.4%**	77.0%	92.7%
Moving	84.2%	**88.2%**	61.9%	72.2%

* Each value in the above tables is an average accuracy of 30 testing videos. The total number of testing frames is approximately 18000.

- *Average ratios and differences for all "0" blocks*

	0°	45°	60°	65°	70°
Ratio	1.0	0.98	0.97	0.95	0.94
Difference	1.0	0.91	0.80	0.67	0.51

Conclusion

- *Develop a model for image formation of an active scene containing electronic displays*
- *Propose photographic steganography method to embed /extract hidden and dynamic message*
- *Achieve high accuracy of message recovery in real world scenes*

Acknowledgement

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