PENNSTATE ARL

Test and Evaluation/Science and Technology Program

Utilization Of Modern Image Processing Techniques To Perform Real-Time Test Evaluation

32nd Annual International Test and Evaluation Symposium

August 20, 2015

Mr. Manuel Gonzalez-Rivero (Technical Lead)
Applied Research Laboratory, The Pennsylvania State University

UNCLASSIFIED

TRMC T&E/S&T Acknowledgement

The algorithms presented here were developed for a use case in support of the Rapid Data Analyzer for Net-Centric Systems Test (RDAN) project.

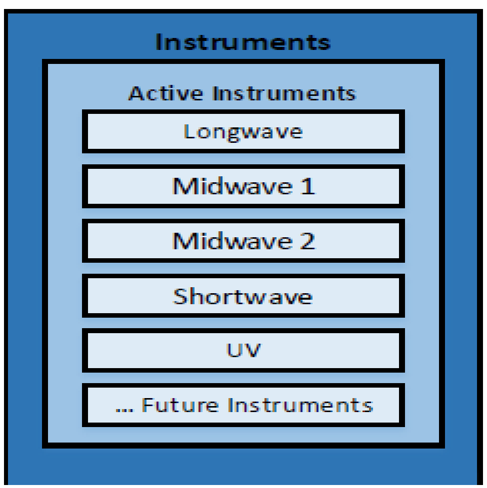
The RDAN project was funded by the Test Resource Management Center (TRMC) Test and Evaluation/Science & Technology (T&E/S&T) Program through the U.S. Army Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) under Contract No. W900KK-13-C-0015.

Outline

- **T&E Need**
- **Problem Space**
- **Algorithms**
- **Summary and Future Work**

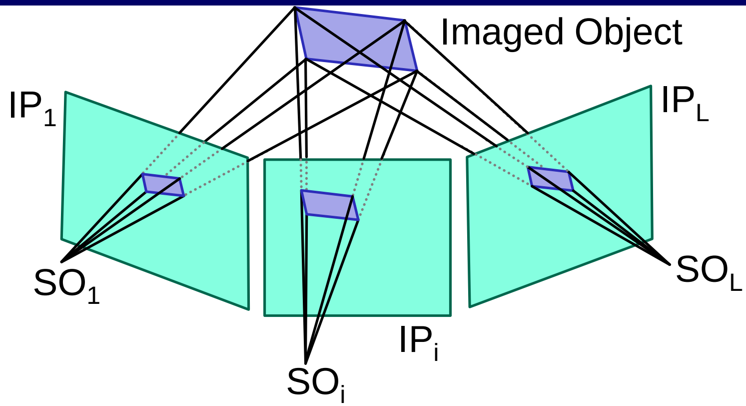
T&E Need
Real-Time Signature Generation and Test Evaluation

- **The use case required the infrared signature measurement of aircraft using data from multiple high speed cameras**
  - Cannot determine validity of collected test data until after test is over
  - Current post-test analysis takes weeks/months to reach a decision
  - Cannot review all data due to large data size and insufficient automation
- **GPU accelerated architecture was proposed to meet these needs**
  - Process data during test event for immediate decision about data validity
  - New algorithms accelerate post-test analysis
  - Automated processing enables expanded review of test data
  - Algorithms can recover useful data from runs that were previously thought unusable



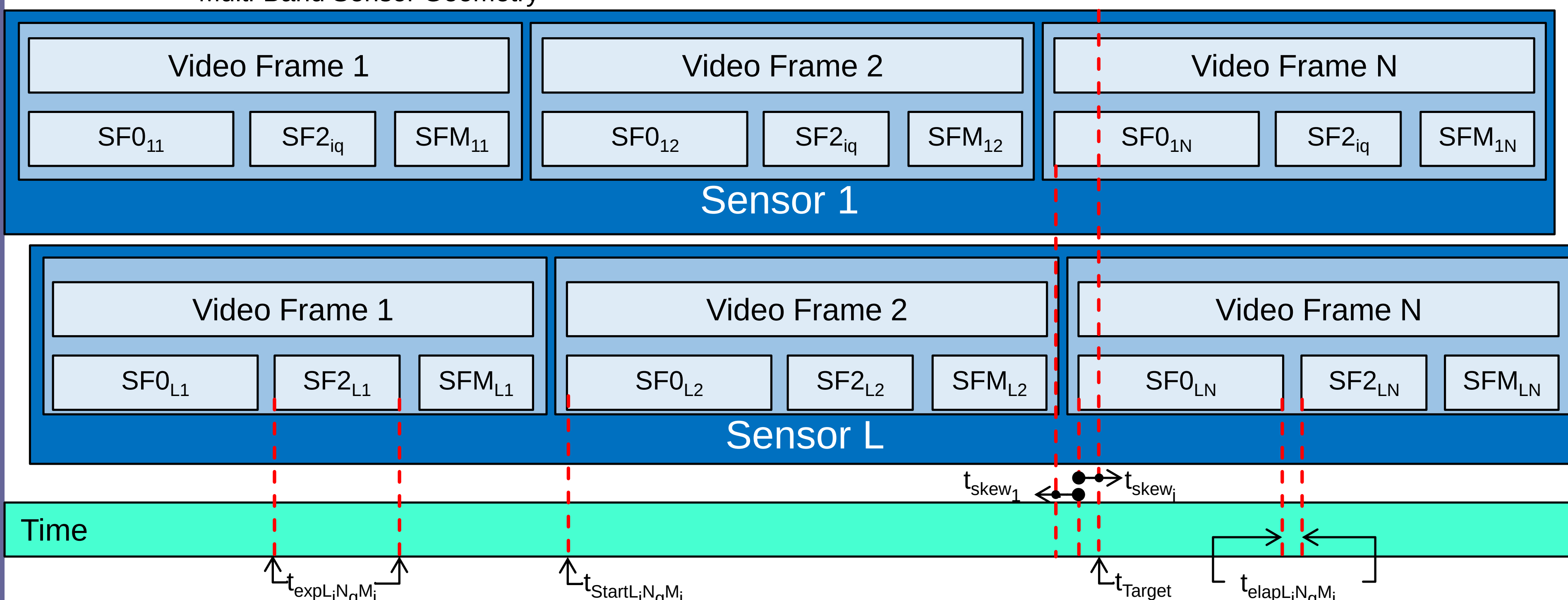
During the process of automating decisions about data validity it was found that data sets that were previously considered invalid could be recovered

Video Problem Space: Geometry

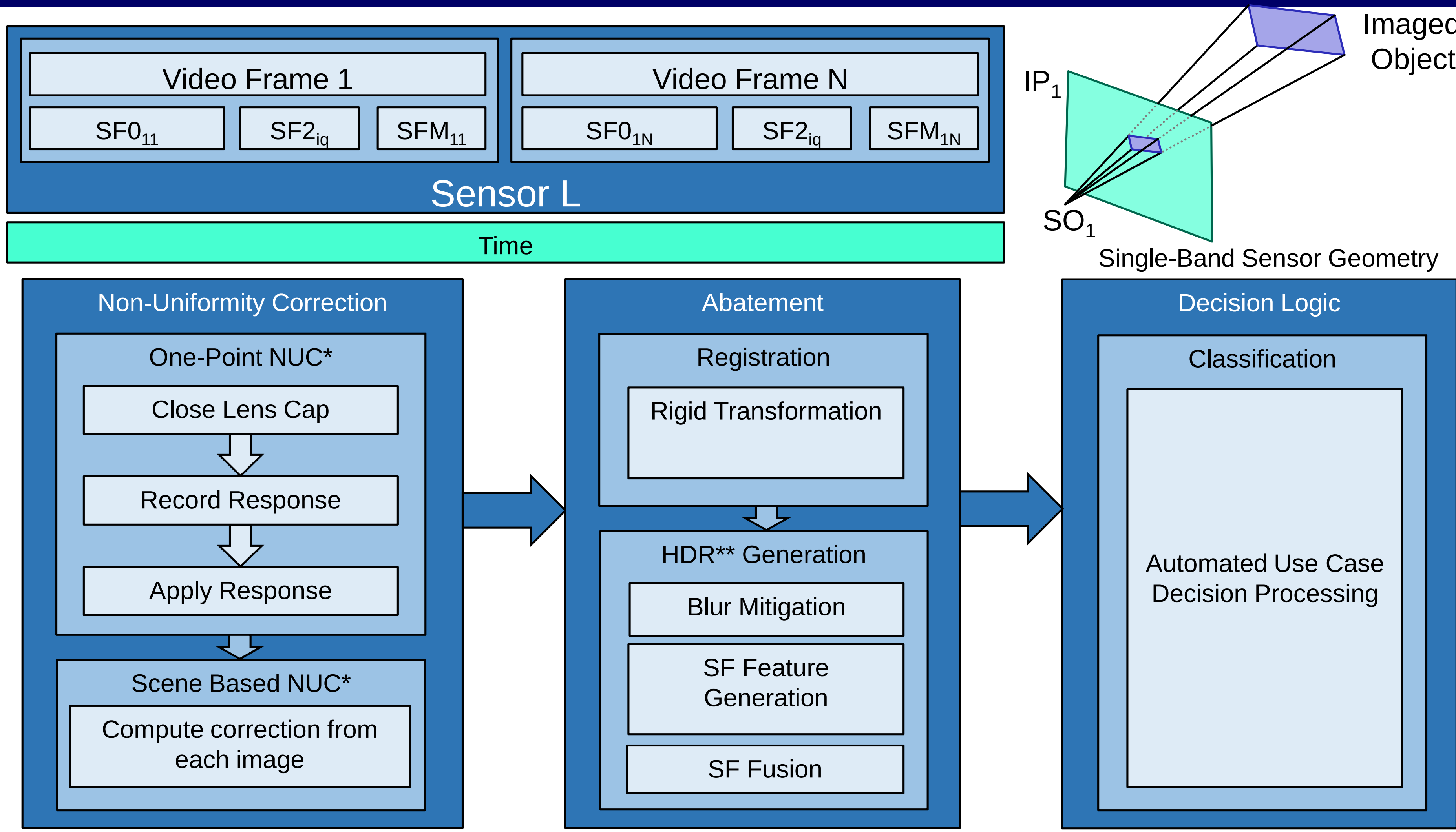


Multi-Band Sensor Geometry

- Object imaged by L sensors form L*N frames per run
- Sensors record frames at periodicity $T_i \quad for\ i = 1 \ldots L$
- Non Co-Located Sensors form IP_i Imaging Planes
- Frames consist of M_{iq} Sub-Frames (SF) $for\ q = 1 \ldots N$
- Sub-Frames are exposed $t_{expL_iN_qM_j}$ secs $for\ j = 1 \ldots M$
- One t_{Target} provided for desired aspect per run
- Min($t_{startSFL_iN_qM_1} - t_{Target}$) is called t_{skew_i}
- Time between SF is called $t_{elapL_iN_qM_j}$



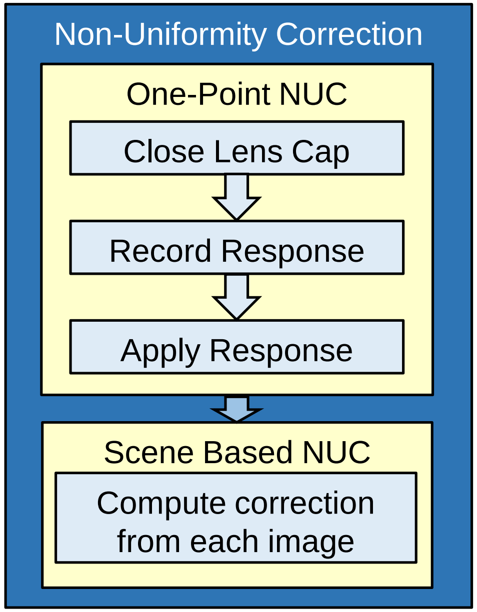
Algorithms: Processing Architecture

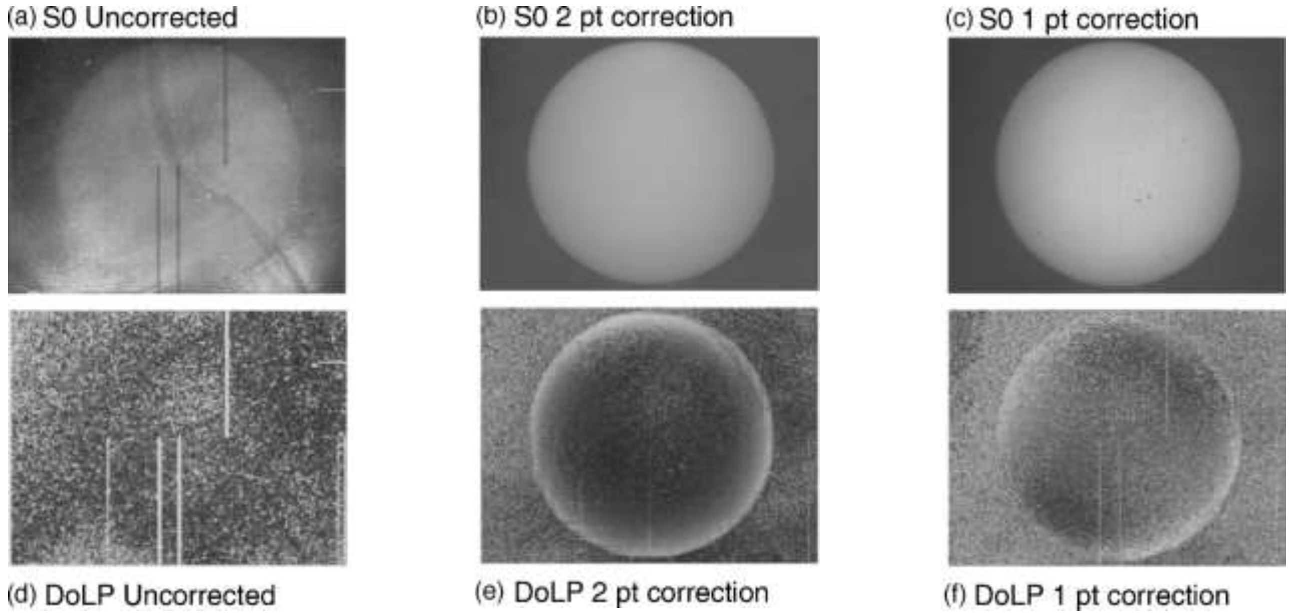


* *Non-Uniformity Correction (NUC)*

** *High Dynamic Range (HDR)*

Algorithms: Non-Uniformity Correction





Two Modalities Corrected

Brass Ball Krylon-Coated

Non-Uniformity is a product of slight variations in pixel element calibration and inconsistencies in the way data is read off the sensor

Some Modalities are more effected than others. Observe SO (Thermal) vs degree-of-linear-polarization (DoLP) image of a krylon coated brass ball

Physical correction can be made by measuring 1 and 2 black body radiators at known temperatures.

Scene based corrections can be made by leveraging image statistics

Algorithms: Non-Uniformity Correction

Non-Uniformity: sigma=20.00, ciRMSE=17.93

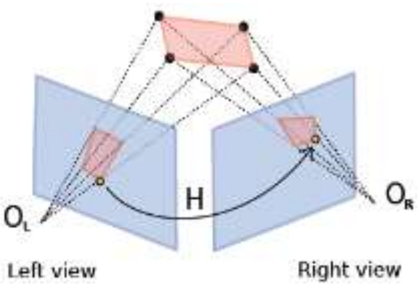
MIRE: sigma=2.53, ciRMSE=9.76

Image can be significantly improved using statistical and physical approaches to NUC

Algorithms: Abatement

Abatement

- **Registration**
  - Rigid Transformation
- **HDR Generation**
  - Blur Mitigation
  - SF Feature Generation
  - SF Fusion



Homographic Projection

- Image Deblurring with Blurred/Noisy Image Pairs – Microsoft Research Asia

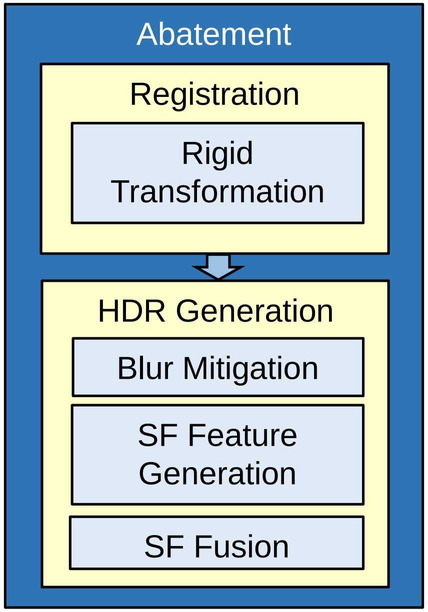
Problem

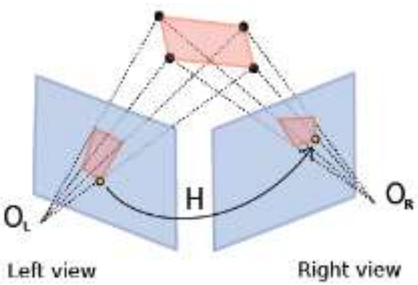
- Long exposures allow imaging of quiet signals (lower fuselage)
- Long exposures susceptible to blurring and saturation
- Short exposure allows sharp imaging of loud signals (engines)
- Short exposures are noisy and cannot capture quiet signals
- Images are not simultaneously captured which causes a deregistration between the images. (i.e. Target features are captured at different coordinates in each SF)

Hypothesis

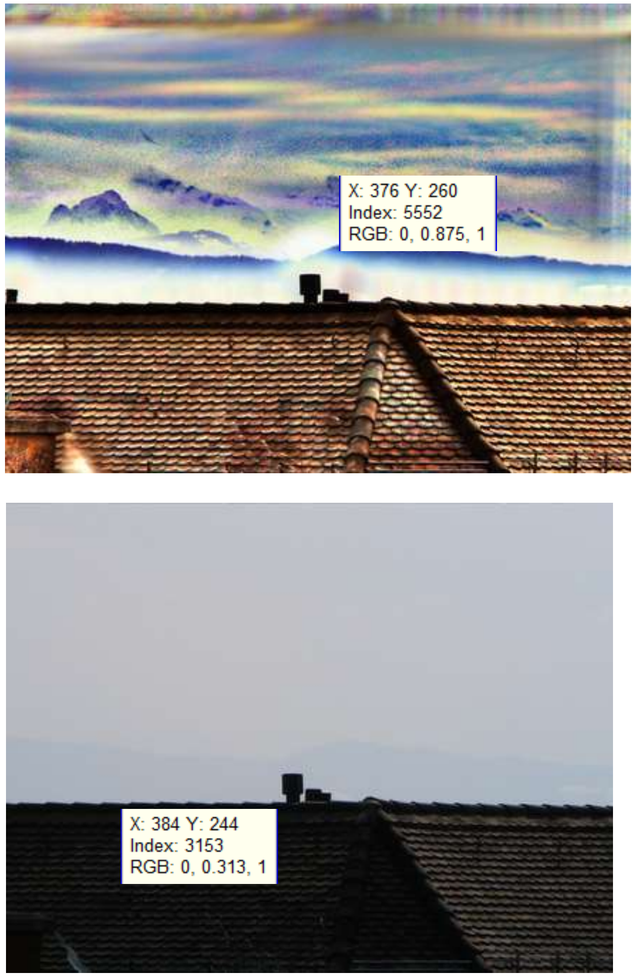
Can the positive qualities of long and short exposures be combined by jointly solving the blur and registration problem to create sharp images that have the largest dynamic range possible?

Algorithms: Registration





Homographic Projection



Un-Registered Sub-Frames

Registration challenge

- Target features are captured at different coordinates in each SF
- Registering blurred images is poorly defined

Solution

- Register blurred images with a rigid transformation initially to get into the ballpark of the solution. We can then use deblurring techniques to correct final registration misalignments

Given:

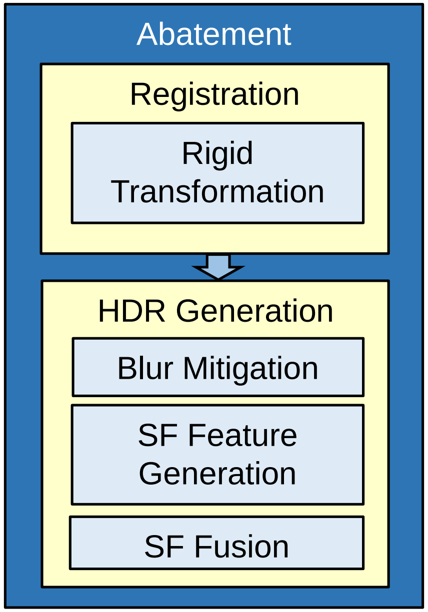
$$\boldsymbol{x}' = [x'_1, x'_2, x'_3]^T \ \textbf{and} \ \boldsymbol{y}' = [y'_1, y'_2, y'_3]^T \in \boldsymbol{P}^2$$
$$\Rightarrow \ \boldsymbol{y}' = \boldsymbol{H}\boldsymbol{x}' \leftrightarrow \boldsymbol{x}' = \boldsymbol{H}^{-1}\boldsymbol{y}',$$

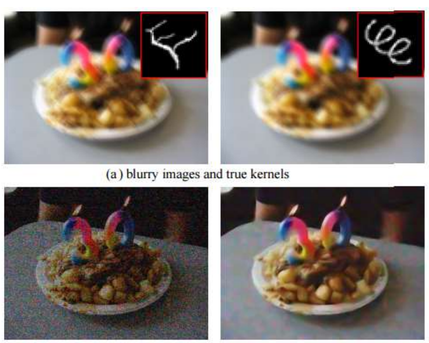
$\boldsymbol{H} = \{\boldsymbol{h}_{ij}\}$ is therefore an unknown 3x3 transformation with 8 degrees of freedom

Constrain H by finding >8 matching pairs of points (modern techniques require >4)

Due to the brief period of time that passes from one frame to the next only rotations, translations, and scale transformations need to be considered

Algorithms: Deblurring




(a) blurry images and true kernels
(b) noisy image
(c) denoised image

Example Observations

- Image Deblurring with Blurred/Noisy Image Pairs – Microsoft Research Asia

Model

$$y_l = k_l * x + n \; \forall l \in \{1, \dots, L\}$$

- l is observation index
- y_l are noisy and blurred observations of the latent image
- x is a sharp and clean latent image to be estimated
- * denotes the convolution operator
- n_l is a zero-mean Gaussian noise term with covariance $\lambda_l I$

GOAL: Estimate the sharp/clean latent image given y_l

Multi-Observation Estimation

Steps:
Initialize k_l
While stopping criteria is not satisfied {

Update $x = \left[\sum_{l=1}^{L} \frac{(H_l^T H_l)}{L\lambda_l} + \Gamma^{-1}\right]^{-1} \sum_{l=1}^{L} \frac{(H_l^T y_l)}{L\lambda_l}$

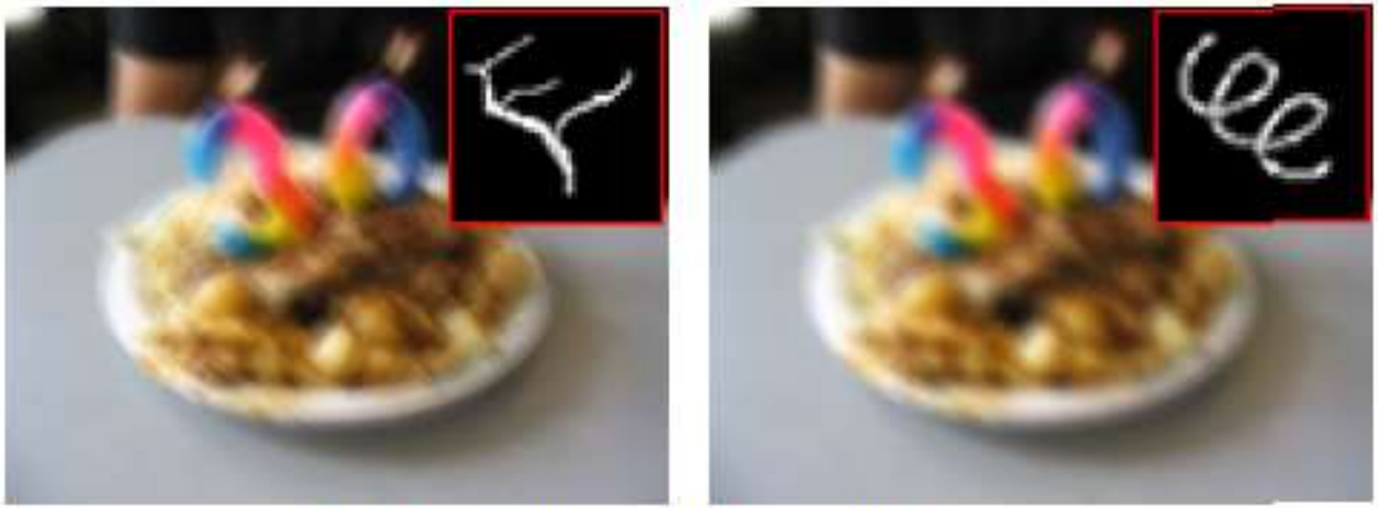
Update $\mathscr{y}_l = x_i^2 + \frac{\sum_{l=1}^{L} z_{li}}{L}, \Gamma^{-1} = diag(\mathscr{y}_l)$

Update $k_l = argmin_{k_l \geq 0} \frac{1}{\lambda_l} \left|\left|y_l - W k_l\right|\right|_2^2 + \sum_j k_{lj}^2 \sum_i z_{il} I_{ji}$

Update $\lambda_l = \frac{\left(|y_l - x * k_l|_2^2 + \sum_j \sum_i k_{lj}^2 z_{il} I_{ji}\right)}{n}$

}

Algorithms: Deblurring



(a) blurry images and true kernels

(b) noisy image (c) denoised image

Distribution Statement A. Approved for public release; distribution is unlimited.

PENNSTATE ARL

Summary

- **Collecting image data in the real world can present many challenges**
  - Non-Uniformity
  - Motion blur
  - Noise from under exposure
  - Registration
- **These challenges can be corrected using image processing techniques to allow:**
  - Processing of data during test events for immediate decisions about data validity
  - Accelerated post-test analysis
  - Expanded review of test data
  - Recovery of useful data from runs that were previously thought to be invalid
- **Plan forward**
  - Continue development into abatement algorithms as funding allows
  - Future development of new parallel algorithms on GPU-accelerated platforms
  - Seek sponsors interested in these new technologies to meet their use case needs

Points of Contact

Mr. Bruce Einfalt
Principal Investigator (PI)
bte2@arl.psu.edu

Manuel Gonzalez-Rivero
Technical Lead
mng3@arl.psu.edu

PENNSTATE ARL

Questions?

PENNSTATE ARL

References

1. Bowers, David L., et al. "Unpolarized calibration and nonuniformity correction for long-wave infrared microgrid imaging polarimeters." *Optical Engineering*47.4 (2008): 046403-046403.
2. Tendero, Y., and J. Gilles. "ADMIRE: a locally adaptive single-image, non-uniformity correction and denoising algorithm: application to uncooled IR camera." *SPIE Defense, Security, and Sensing*. International Society for Optics and Photonics, 2012.
3. Tendero, Yohann, Stéphane Landeau, and Jérome Gilles. "Non-uniformity correction of infrared images by midway equalization." *Submitted to Image Processing On Line* (2012): 1-23.
4. Vickers, Virgil E. "Plateau equalization algorithm for real-time display of high-quality infrared imagery." *Optical engineering* 35.7 (1996): 1921-1926.
5. Lanza, Alessandro, Federico Tombari, and Luigi Di Stefano. "Robust and efficient background subtraction by quadratic polynomial fitting." *Image Processing (ICIP), 2010 17th IEEE International Conference on*. IEEE, 2010.
6. Kriegman, David. "Homography Estimation." *Lecture Computer Vision I, CSE A*252 (2007).
7. Zhang, Haichao, David Wipf, and Yanning Zhang. "Multi-observation blind deconvolution with an adaptive sparse prior." *Pattern Analysis and Machine Intelligence, IEEE Transactions on* 36.8 (2014): 1628-1643.
8. Srinivasa, Gowri, et al. "Active mask segmentation for the cell-volume computation and Golgi-body segmentation of HeLa cell images." *Biomedical Imaging: From Nano to Macro, 2008. ISBI 2008. 5th IEEE International Symposium on*. IEEE, 2008.
9. Yuan, Lu, et al. "Image deblurring with blurred/noisy image pairs." *ACM Transactions on Graphics (TOG)* 26.3 (2007): 1.