



# Multi-spectral Fusion for Indoor and Outdoor Face Authentication

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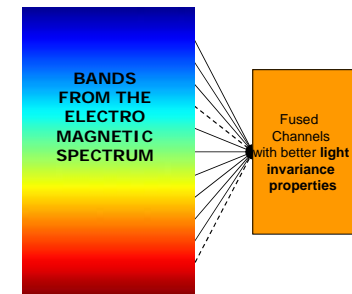
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## Outline



- Introduction
- Experimental set ups
- Database description
- Algorithms
- Data and result analysis
- Conclusion



## Introduction



- Acquisition of an **indoor and an outdoor database** of multispectral images under various illuminants
- Use of a **Liquid Crystal Tunable Filter (LCTF)** coupled to a video camera to generate *multi-spectral* registered data
- Develop **fusion** methods of multiple spectral channels for a more robust **indoor/outdoor** face recognition (better invariance to nature and direction of illuminant)
- **Conventional B/W images** used as **gallery** to test the multi spectral probes and **Facelt G6** used for recognition
- Munsell Color Science Lab initiated the use of LCTF for multispectral imaging of art work
- Pan et al. studied spectral face images in the NIR

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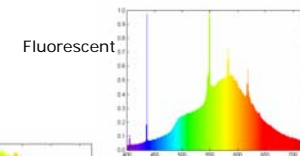
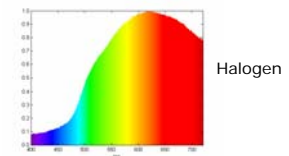
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## Data Acquisition Sessions



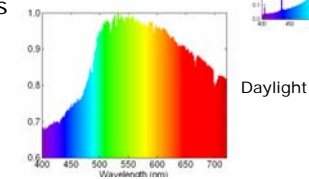
### Semester – 1 Indoor

- Session 1 - Homogeneous
  - Halogen black and white (B/W)
  - Halogen Multi Spectral (MS)
- Session 2 - Homogeneous
  - Fluorescent B/W
  - Fluorescent MS



### Semester – 2 Indoor/Outdoor

- Session 3 - Homogeneous
  - Fluorescent B/W
- Session 3 – Side Light
  - Daylight B/W
  - Daylight MS



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## Indoor/Outdoor Setups



S1H: Halogen light: 5 kLux



### Equipment:

- Video camera
- Liquid Crystal Tunable Filter 400-720nm
- Frame grabber
- Computer
- Various light settings
- Height adjustable Chair and head rest
- Spectrometer
- IR and NIR cameras

S3D: Day light: 80 kLux



### Filter:

Aperture: 35mm  
Bandwidth: 7nm  
Range: 400-720nm

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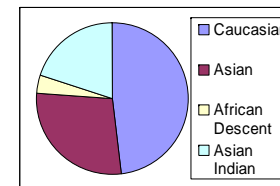
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## Data Acquired




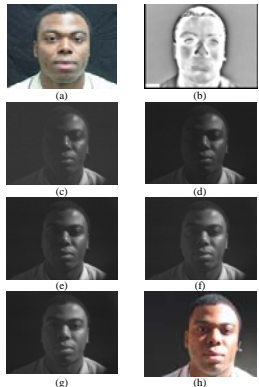
Illuminant	participants	Male	Female	Caucasian	Asian	African Descent	Indian
Halogen S1H_BW S1H_MS	50	36	14	24	13	2	11
Fluorescent S2F_BW S2F_MS	25	19	6	12	7	1	5
Side Daylight S3D_BW S3D_MS	67	48	19	36	16	5	10

- Sequences of 25/13 images in different spectral channels (visible) plus one image without filter and one thermal image for each person
- Indoor images are used for gallery
- ~ 3000 face images in database




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A set of images in a **data record** in our database: (a) visible RGB image under fluorescent light, (b) thermal image, (c)-(g) MSI band images, with wavelengths centered at 0.48  $\mu\text{m}$ , 0.54  $\mu\text{m}$ , 0.60  $\mu\text{m}$ , 0.66  $\mu\text{m}$  and 0.72  $\mu\text{m}$ , (h) outdoor visible RGB image in daylight with side illumination.

Examples of **participants**: (a) male Asian, (b) female Caucasian, (c) female of African descent, (d) male Asian Indian, (e) female Asian, (f) male Caucasian (all under fluorescent light).




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## Algorithms and Experiments



- Data fusion approaches
  - Weighted Wavelet
  - Principal Components Analysis
  - Averaging
  - Physics-based Fusion
    - Spectral distribution of illuminant
    - Transmittance of filter
  - Illumination Compensation
- **Experiment 1: between semesters**
  - Gallery: S1H\_BW
  - Probes:
    - S3F\_BW
    - S3D\_BW
    - Single channels S3D\_MS
    - Channel fusion on S3D\_MS
- **Experiment 2: between semesters**
  - Gallery: S3F\_BW
  - Probes:
    - S1H\_BW
    - Single channels of S1H\_MS
    - Channel fusion on S1H\_MS
- **Experiment 3: within semester**
  - Gallery: S2F\_BW
  - Probes:
    - S1H\_BW
    - Single channels of S1H\_MS
    - Channel fusion on S1H\_MS

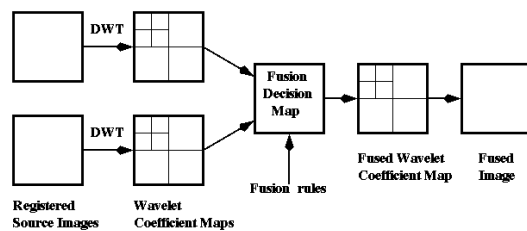


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## Weighted Wavelet Fusion



- Fusion of two images using weighted wavelet coefficients



$A = a1 \cdot A_{i1} + b1 \cdot A_{i2}$ ; % **A** is the approximation coefficient of the fused image  
 $D = a2 \cdot D_{i1} + b2 \cdot D_{i2}$ ; % **D** is the detail coefficient of the fused image

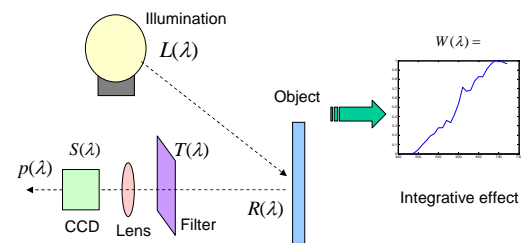
**a1** is the **weight** of wavelet approximation coefficient of image 1  
**b1** is the **weight** of wavelet approximation coefficient of image 2  
**a2** is the **weight** of wavelet detail coefficient of image 1  
**b2** is the **weight** of wavelet detail coefficient of image 2

[http://www.eecs.lehigh.edu/SPCRL/IF/image\\_fusion.htm](http://www.eecs.lehigh.edu/SPCRL/IF/image_fusion.htm)

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## Physics-Based Weighted Fusion



1. Emphasizes bands with more information and oppresses the bands with less information and low SNR.

$$I = \frac{\sum_{i=1}^N W(\lambda_i) \cdot I_i}{\sum_{i=1}^N W(\lambda_i)}$$

2. Intensity compensation  
Ideal flat transmittance

$$W(\lambda_i) = \frac{1}{W(\lambda_i)}$$

### • Weights used

- W1\_T: transmittance of filter
- W2\_T: reciprocal of W1\_T
- W1\_LT: Illumination and transmittance of filter
- W2\_LT: reciprocal of W1\_LT

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## Illumination Compensation Fusion



- If the camera response, the filter transmittance, and the reflectance are the same, and the illuminants represent the only difference:

$$p_1 = L_1 \cdot RST \quad p_2 = L_2 \cdot RST$$

- Image under 2<sup>nd</sup> illuminant would look like an image under the 1<sup>st</sup> illuminant by applying:

$$p_{2 \rightarrow 1} = \frac{L_1}{L_2} p_2 \quad w_{12} = \frac{L_1}{L_2}$$

- Illumination compensation fusion:

$$P = \sum_{i=1}^N w_{12,i} P_{A_i} / \sum_{i=1}^N w_{12,i}$$

### Performance measures:

- CMC curves
- First rank recognition rate
- CMC metric:

$$Q_{CMC} = \frac{1}{N} \sum_{i=1}^M C_i / i$$

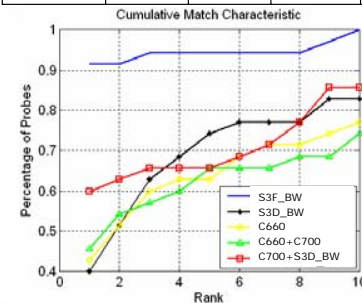
where  $M$  is gallery size,  $N$  is the probe size,  $C_i$  is the number of probe images that can be correctly identified at (but not above) rank  $i$

## study 1 – Between Semesters Outdoor Side Light Probes



### BW, Single Channel, and Wavelet Fusion

Gallery	Probe 00	Probe 0	Probe 1	Probe 2	Probe 3	Probe 4
S1H_BW	S3F_BW Homogeneous light	S3D_BW Side daylight	S3D_C660 Side daylight	S3D_C700 Side daylight	Wavelet fusion S3D_C660 S3D_C700	Wavelet fusion S3D_C700 S3D_BW
Rank 1	91.4%	40%	42.9%	42.9%	45.7%	60%
CMC metric	93%	53.2%	52.7%	54.3%	53.7%	64.9%



- S3F\_BW is an indoor gallery acquired under bright homogeneous fluorescent lighting
- S3D\_BW is the outdoor probe with side lighting
- Homogeneous illumination provides much better recognition rates than inhomogeneous illumination

Sample Images from study 1



Gallery: S1H\_BW



S3F\_BW - 91.2%



S3D\_BW - 40%



S3D\_C700 - 42.9%



S3D\_C660 - 42.9%



Wavelet C660+C700  
45.7%



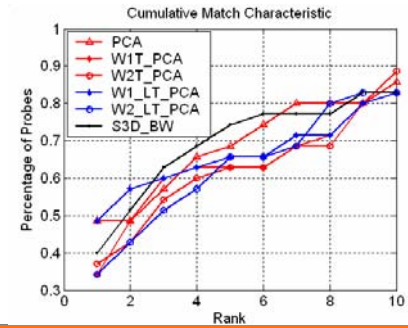
Wavelet C700+S3D\_BW  
60%

study 1 - Between Semesters Outdoor Side Light Probes



Physics-based Fusion

Gallery	Probe 0	Probe 1	Probe 2	Probe 3	Probe 4	Probe 5
S1H_BW	S3D_BW	S3D_MS PCA	S3D_MS W1T	S3D_MS W2T	S3D_MS WILT	S3D_MS W2LT
Rank 1	40%	48.6%	34.3%	37.1%	48.6%	34.3%
CMC metric	53.2%	57.6%	49.6%	49.5%	58.5%	47.9%

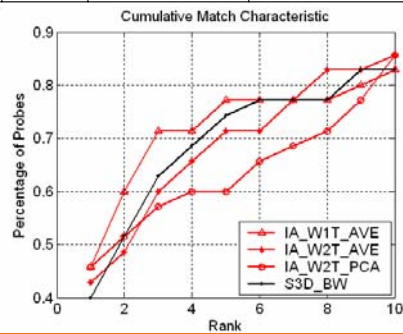


## study 1 – Between semesters Outdoor Side Light probes



### Illumination Adjustment Weighted Fusion

Gallery	Probe 0	Probe 1	Probe 2	Probe 3
S1H_BW	S3D_BW	S3D_MS→S1H_MS WIT-AVE.	S3D_MS→S1H_MS W2T-AVE.	S3D_MS→S1H_MS W2T-PCA
Rank 1	40%	45.7%	42.9%	45.7%
CMC metric	53.2%	59.7%	54.8%	55.5%



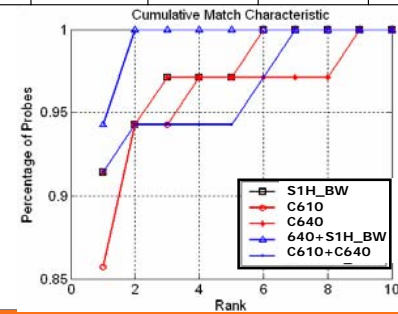
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## study 2 – Between Semesters Indoor Homogeneous Probes



### BW/Single Channel/Wavelet Fusion





Gallery	Probe 0	Probe 1	Probe 2	Probe 3	Probe 4
S3F_BW	S1H_BW Homogeneous light	S1H_C640 Homogeneous light	S1H_C610 Homogeneous light	Wavelet fusion S1H_C610 S1H_C640	Wavelet fusion S1H_C640 S1H_BW
Rank 1	91.4 %	91.4%	85.7%	91.4%	94.3 %
CMC metric	93.7%	94.3%	91.2%	94.1%	97.1%




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Sample Images from study 2

Gallery: S3F\_BW

S1H\_BW 91.4%


S1H\_C640 91.4%

S1H\_C610 85.7%


Wavelet C610+C640 91.4%

Wavelet C640+S1H\_BW 94.3%

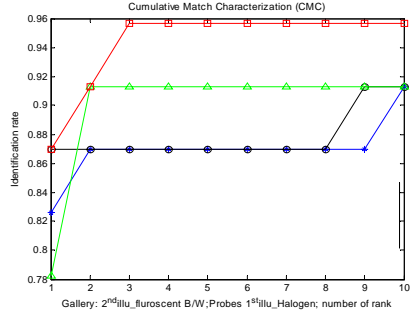
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### study 3 – Within Semester Indoor Homogeneous Probes – Facet G3



Cumulative Match Characterization (CMC)



Identification rate


Gallery: 2<sup>nd</sup>flu\_fluorescent B/W: Probes 1<sup>st</sup>flu\_Halogen; number of rank

Legend:

- S1H\_BW (Green line)
- MSI PCA S1H\_C (Blue line)
- MSI Ave S1H\_C (Black line)
- S1H\_C → S2F\_C (Red line)

Gallery	Probe 0	Probe 1	Probe 2	Probe 3
S2F_BW	S1H_BW 78%	PCA S1H_MS 82.5%	Average S1H_MS 87%	Illumination compensation from S1H to S2F 87%

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## Rank-level Fusion



### Between semesters study 1

- Gallery - indoor homogeneous light
- Probes - outdoor side daylight with shadows

Gallery	Probe 0	Probe 1	Probe 2	Probe 3	Probe 4	Probe 5
S1H_BW	<b>S3D_BW</b>	Wavelet fusion S3D_C660 S3D_C700	Rank fusion S3D_C660 S3D_C700	Wavelet fusion S3D_C700 S3D_BW	Rank fusion S3D_C700 S3D_BW	<b>Rank fusion S3D_C... S3D_BW</b>
Rank 1 CMCM	<b>40%</b> <b>53.2%</b>	45.7% 53.7%	54.3% 66.2%	60% 64.9%	54.3% 67.7%	<b>71.4%</b> <b>83.2%</b>

### Between semesters study 2

- Gallery – indoor homogeneous fluorescent light
- Probes – indoor homogeneous halogen light

Gallery	Probe 0	Probe 1	Probe 2	Probe 3	Probe 4	Probe 5
S3F_BW	<b>S1H_BW</b>	Wavelet fusion S1H_C610 S1H_C640	Rank fusion S1H_C610 S1H_C640	Wavelet fusion S1H_C640 S1H_BW	Rank fusion S1H_C640 S1H_BW	<b>Rank fusion S1H_C640 S1H_C610 S1H_BW</b>
Rank 1	<b>91.4 %</b>	91.4%	94.3%	94.3 %	97.1%	<b>100 %</b>

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## Results Summary



Gallery	Probe	Time Gap	Illumination	Best channel	Best data fusion	BW to fusion rates	Rank fusion
S3F_BW	S3D	None	Inhomogeneous	680	N/A	All 100%	----
S1H_BW	S3D	5 months	Inhomogeneous	700	<b>Wavelet: S3D_C720 and S3D_BW</b> <b>50% improvement</b>	40% to 60%	40% to 71.4% <b>78.5% improvement</b>
S3F_BW	S1H	5 months	Homogeneous	---	<b>Wavelet: 640 and S1H_BW</b> <b>3.2% improvement</b>	91.4% to 94.3%	91.4% to 100% <b>9.5% improvement</b>
S2F_BW	S1H	20 days	Homogeneous	---	Not much improvement 11.5% improvement by MS fusion and Facelt G3	All 95.6% 78% to 87%	----

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## Conclusions



- Fusion of individual channels yields better results than BW alone.
- Best results for data fusion are obtained, both for indoor and outdoor, when the best performing spectral channel is fused with the BW image using weighted wavelets.
- Rank-level fusion is the overall best performer.
- Most noticeable improvement happens for the outdoor probe with side lighting and time gap - up to 78.5% increase for rank 1.
- The effect of time gap between gallery and probe is more important than the effect of illumination variations (for Facelt G6).
- Drastic drop in recognition rates when the probe's illumination is non homogeneous.

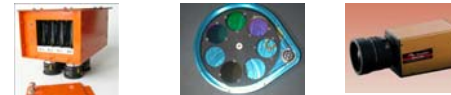
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## Conclusions



- Good potential for use of multispectral data in addition to conventional intensity images to increase recognition rates, especially under inhomogeneous daylight illumination.
- Higher sensitivity multispectral cameras can be used and are expected to yield even larger improvements in recognition rates.
- Additional analysis will be conducted towards the justification of some fusion results and the establishing of best performing channels.



Some commercial multispectral  
Cameras and systems

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