Multispectral Image Fusion and Colorization

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Multispectral Image Fusion and Colorization

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To my family, for their encouragement and support.
—*Yufeng Zheng*

To my sons, Vojtech, Matej, and Ondrej, for their interest in science.
— *Erik Blasch*

To the families of Hanasaki in Osaka, Japan.
— *Zheng Liu*

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Preface

Over the past two decades, there have been a growing number of image fusion solutions; however, there has not been a comprehensive book from which to teach standard image fusion methods. There are very few books that follow a textbook style that elaborates the entire process, from concepts and theory to evaluation and application, that would be useful to train beginners.

This book was written to provide readers with an understanding of image fusion techniques with basic principles, common examples, and known methods. Although not all methods are extensively covered, the book aims to provide students, practitioners, and researchers with a background in proven techniques. Undergraduate training in engineering or science is recommended to appreciate concepts such as linear algebra and image processing.

The second motivation for the text is to organize the terminology, results, and techniques. The book and the associated software provide readers with the opportunity to explore common image fusion methods, such as how to combine multiband images to enhance computer vision and human vision for applications such as face recognition and scene understanding.

The third motivation is to provide a baseline for the performance evaluation of image fusion methods. Most publications concentrate on image fusion methods, although some quality metrics are used for comparison. Very few publications provide a comprehensive overview of fusion metrics and a comparison of objective metrics and subjective evaluations. Throughout this book, examples are shown and an array of metrics are presented that help establish the capabilities of image fusion. Different motivational applications might use some or none of the metrics, but the goal of the book is to formalize image fusion evaluation.

Multispectral image fusion and night-vision colorization are organized into four areas: (1) concepts, (2) theory, (3) evaluation, and (4) applications. Two primary multiscale fusion approaches—the image pyramid and wavelet transform—are elaborated with several examples, including face matching, biomedical imaging, and night vision. Using these examples, multiple-level fusion is demonstrated for pixel-, feature-, score-, and decision-level fusion. Image fusion comparisons are highlighted, including data, metrics, and analytics. Finally, the book addresses a topic not highlighted elsewhere: techniques for evaluation, either objectively with computer metrics or subjectively by human users. An appendix includes online resources, including example data and code.

Part I includes three chapters to present the background information and basic concepts of image fusion. Part II describes image fusion theory in four chapters.

Part III consists of two chapters dedicated to quantitative evaluation and qualitative evaluation. Part IV presents several fusion applications illustrated with off-focal, medical, terahertz, night-vision, and facial images.

The idea to write a book was inspired by a SPIE short course— "Multispectral Image Fusion and Night Vision Colorization"—taught by Zheng and Blasch at the SPIE Defense and Commercial Sensing conference since 2014. There was also interest in a summary of night-vision-colorization techniques due to the growing needs of commercial operations. The comparison and evaluation of these techniques are unique features of this book. This is the first comprehensive text for teaching image fusion, and we hope others improve on the techniques to make image fusion methods more common.

Yufeng Zheng
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Zheng Liu
March 2018

List of Acronyms

AC	Accuracy
ACR	Accuracy rate
*a*DWT	Advanced discrete wavelet transform
*a*DWTi	Iterative advanced discrete wavelet transform
ASUDC	Alcorn State University digital camera (visible face data)
ASUIR	Alcorn State University infrared (infrared face data)
ASUMSS	Alcorn State University multispectral stereo (dataset)
ANN	Artificial neural network
ANOVA	Analysis of variance
AOI	Area of interest
AOS	Additive operator splitting
ARC	Absolute rate change
ATC	Automatic target classification
ATR	Automatic target recognition
BFLD	Block-based Fisher's linear discriminant
BLR	Binomial logistic regression
BN	Bayesian network
BNEM	Bootstrapping nonparametric expectation maximization
CAD	Computer-aided detection
CBCF	Channel-based color fusion
CC&D	Camouflage, concealment, and detection
CCD	Charge-coupled device
CGF	Circular Gaussian filter
CIE	International Commission on Illumination
CIFM	Color image fusion measure
CM	Confusion matrix
CNM	Color natural metric
CNN	Convolutional neural network
CPF	Color-based particle filtering tracker
CPU	Central processing unit
CRT	Continuous ridgelet transform
CS	Compressive sensing
CT	Computed tomography
DC	Direct current
DF	Decision fusion

DFB	Directional filter bank
DFIG	Data Fusion Information Group (model)
DL	Daylight (images)
DLF	Decision-level fusion
DOE	Design of experiments
DOG	Difference of Gaussians
DRCI	Detection, recognition, classification, and identification
DS	Dempster–Shafer
DSmT	Dezert Smarandache Theory
DT-CWT	Dual-tree complex wavelet transform
DWF	Discrete wavelet frame
DWT	Discrete wavelet transform
EBGM	Elastic bunch graph matching
EM	Expectation maximization
EMD	Empirical mode decomposition
EO	Electro-optical
EOC	Extending operating conditions
FAR	False-accept rate (face recognition)
FAR	False-alarm rate
FCM	Fuzzy clustering means
FDCT	Fast discrete curvelet transform
FFT	Fast Fourier transform
FLIR	Forward-looking infrared
FOV	Field of view
FP-CGF	Face-pattern circular Gaussian filter
FPB	Face pattern byte
FF	Feature fusion
FPSS	Force-protection surveillance system
FPW	Face pattern words
FRAT	Finite radon transform
FRC	False rejection rate
FRIT	Finite ridgelet transform
FRR	False rejection rate (face recognition)
FSD	Filter–subtract–decimate
GA	Genetic algorithm
GAR	Genuine accept rate
GCD	Gabor cancer detection
GIQ	General image quality
GM	Gradient magnitude
GMM	Gaussian mixture model
GQM	Global quality map
GRA	Gray relational analysis
GUI	Graphical user interface
GWT	Gabor wavelet transform
HD	Hamming distance

HMM	Hidden Markov model
HR	High resolution
HR	Hit rate
HOG	Histogram of oriented gradients
HOSVD	Higher-order singular value decomposition
HSI	Hyperspectral imagery
HSV	Hue, saturation, value (brightness)
ICA	Independent component analysis
ID	Identity declaration
IF	Image fusion
HIS	Intensity, hue, saturation
ICM	Image contrast metric
IFFT	Inverse fast Fourier transform
II	Image intensified
INI	Image noise index
IQ	Image quality
IQI	Image quality index
JDL	Joint director of the laboratory (fusion model)
JHM	Joint histogram matching
JSM	Joint sparsity model
KNN	*k*-nearest neighbor
LAB ($l\alpha\beta$)	Luminance (L, brightness), red–green chrominance (α), yellow–blue chrominance (β)
LBP	Local binary pattern
LCD	Liquid crystal display
LDA	Linear discriminant analysis
LDF	Linear discriminant function
LGN	Lateral geniculate nucleus
LGXP	Local Gabor XOR patterns (operator)
LMS	log L, log M, log S
LMS	Long-wave, mid-wave, and short-wave (infrared)
LOG	Laplacian of Gaussian
LP (LAP)	Laplacian pyramid
LR	Logistic regression
LR	Low resolution
LTP	Local ternary pattern
LUT	Lookup table
LWIR	Long-wave infrared
LXP	Local XOR pattern (operator)
MBSF	Multimodal biometric score fusion
MI	Mutual information
mL1-PF	Multisensor L1 particle filter (tracker)
MLR	Multinomial logistic regression
MOD	Method of optimal directions
MPF	Manifold-based particle filtering tracker

MRA	Multiresolution analysis
MRF	Markov random field
MRI	Magnetic resonance imaging
MS	Mean-shift (tracker)
MSDF	Multispectral decision fusion
MSFF	Multispectral feature fusion
MSI	Multispectral imagery
MSIF	Multispectral image fusion
MSSF	Multispectral score fusion
MT	Middle temporal
MWIR	Mid-wave infrared
NAI	Named area of interest
NASA	National Aeronautics and Space Administration
NCC	Nonlinear correlation coefficient
NCIE	Nonlinear correlation information entropy
NIR	Near-infrared
NIIRS	National Imagery Interpretability Rating Scale
NMI	Normalized mutual information
NN	Nearest neighbor
NSCT	Non-subsampled contourlet transform
NV	Night vision
OCs	Operating conditions
OEI	Objective evaluation index
OMP	Orthogonal matching pursuit
PAN	Panchromatic
PC	Phase congruency (model)
PCA	Principal component analysis
PCC	Probability of correct classification
PCM	Phase congruency metric
PCNN	Pulse coupled neural network
PCR	Proportional conflict resolution
PDE	Partial differential equation
PDF	Probability density function
PDFB	Pyramidal directional filter bank
PET	Positron-emission tomography
PRF	Pulse repetition frequency
PSNR	Peak signal-to-noise ratio
RBFN	Radial basis function network
RGB	Red, green, blue channels
RMSE	Root mean square error
ROC	Receiver operating characteristic (curve)
ROI	Region of interest
ROLP	Ratio of low-pass
RRC	Relative rate change
RRI	Relative rate increase

rSFe	Ratio of spatial frequency error
SAR	Synthetic aperture radar
SBA	Shape-based averaging
SBH	Simulation of the functions of bipolar and horizontal cells
SBM	Single best matcher
SF	Score fusion (method)
SF	Spatial frequency (metric)
SFr	Spatial frequency ratio
SFR	Spherical face representation
SGA	Simulation of the functions of ganglion and amacrine
SIDWT	Shift-invariant discrete wavelet transform
SIFT	Scale-invariant feature transform
SM	Statistic matching
SM-JHM	Statistic matching and then joint histogram matching
SNR	Signal-to-noise ratio
SOC	Standard operating conditions
SPSS	Statistical Package for the Social Sciences (software package now called IBM SPSS Statistics)
SR	Sparse representation
SRDF	Stereo decision fusion
SRFF	Stereo feature fusion
SRIF	Stereo image fusion
SRSF	Stereo score fusion
SSIM	Structural similarity index metric
SUM	Sensor, user, and management
SURF	Speeded-up robust feature
SVD	Singular value decomposition
SVM	Support vector machine
TIFT	Terahertz imaging focal-plane technology
TPR	True positive rate
TV	Total variation
UAV	Unmanned aerial vehicle
UIQI	Universal image quality index
USFFT	Unequally spaced fast Fourier transform
UV	Ultraviolet
VCM	Visual cortex module
WAMI	Wide-area motion imagery