

# **MULTI-DIMENSIONAL IMAGING**

# MULTI-DIMENSIONAL IMAGING

Edited by

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*For Bethany, Ariana, Darius, and Vida*

*In memory of our friend and colleague, Dr Fumio Okano*

# Contents

<b>About the Editors</b>	<b>xv</b>
<b>List of Contributors</b>	<b>xvii</b>
<b>Preface</b>	<b>xxi</b>
<b>Acknowledgments</b>	<b>xxiii</b>

## **Part I MULTI-DIMENSIONAL DIGITAL HOLOGRAPHIC TECHNIQUES**

<b>1</b>	<b>Parallel Phase-Shifting Digital Holography</b>	<b>3</b>
	<i>Yasuhiro Awatsuji</i>	
1.1	Chapter Overview	3
1.2	Introduction	3
1.3	Digital Holography and Phase-Shifting Digital Holography	4
1.4	Parallel Phase-Shifting Digital Holography	6
1.5	Experimental Demonstration of Parallel Phase-Shifting Digital Holography	8
1.6	High-Speed Parallel Phase-Shifting Digital Holography System	12
1.7	Single-Shot Femtosecond-Pulsed Parallel Phase-Shifting Digital Holography System	14
1.8	Portable Parallel Phase-Shifting Digital Holography System	17
1.9	Functional Extension of Parallel Phase-Shifting Digital Holography	17
	1.9.1 <i>Parallel Phase-Shifting Digital Holography Using Multiple Wavelengths</i>	18
	1.9.2 <i>Parallel Phase-Shifting Digital Holography Using Multiple Polarized Light</i>	19
	1.9.3 <i>Parallel Phase-Shifting Digital Holographic Microscope</i>	20
1.10	Prospects and Conclusion	20
	Acknowledgments	20
	References	21

<b>2</b>	<b>Imaging and Display of Human Size Scenes by Long Wavelength Digital Holography</b>	<b>25</b>
	<i>Massimiliano Locatelli, Eugenio Pugliese, Melania Paturzo, Vittorio Bianco, Andrea Finizio, Anna Pelagotti, Pasquale Poggi, Lisa Miccio, Riccardo Meucci and Pietro Ferraro</i>	
2.1	Introduction	25
2.2	Digital Holography Principles	25
	2.2.1 <i>Fresnel Method</i>	29
	2.2.2 <i>Advantages of Digital Holography</i>	31
2.3	Infrared Digital Holography	33
2.4	Latest Achievements in IRDH	34
	2.4.1 <i>Super Resolution by Means of Synthetic Aperture</i>	35
	2.4.2 <i>Human Size Holograms</i>	38
	2.4.3 <i>Visible Analog Reconstruction of IR Digital Holograms</i>	40
	2.4.4 <i>Smoke and Flames Hidden Object Holograms</i>	43
2.5	Conclusion	46
	References	47
<b>3</b>	<b>Digital Hologram Processing in On-Axis Holography</b>	<b>51</b>
	<i>Corinne Fournier, Loïc Denis, Mozhdeh Seifi and Thierry Fournel</i>	
3.1	Introduction	51
3.2	Model of Hologram Image Formation	52
3.3	DH Reconstruction Based on Back Propagation	56
3.4	Hologram Reconstruction Formulated as an Inverse Problem	57
	3.4.1 <i>Reconstruction of Parametric Objects (FI)</i>	59
	3.4.2 <i>Reconstruction of 3-D Transmittance Distributions (FII)</i>	62
3.5	Estimation of Accuracy	64
3.6	Fast Processing Algorithms	65
	3.6.1 <i>Multiscale Algorithm for Reconstruction of Parametric Objects</i>	65
	3.6.2 <i>Dictionary Size Reduction for Fast Global Detection</i>	68
3.7	Conclusion	69
	References	70
<b>4</b>	<b>Multi-dimensional Imaging by Compressive Digital Holography</b>	<b>75</b>
	<i>Yair Rivenson, Adrian Stern, Joseph Rosen, and Bahram Javidi</i>	
4.1	Introduction	75
4.2	Compressive Sensing Preliminaries	76
	4.2.1 <i>The Coherence Parameter</i>	78
4.3	Conditions for Accurate Reconstruction of Compressive Digital Holographic Sensing	79
	4.3.1 <i>Compressive Sensing Reconstruction Performance for a Plane Wave Illuminated Object</i>	79
	4.3.2 <i>Compressive Sensing Reconstruction Performance for a Spherical Wave Illuminated Object</i>	81
	4.3.3 <i>Reconstruction Performance for Non-Canonical Sparsifying Operators</i>	83

4.4	Applications of Compressive Digital Holographic Sensing	84
4.4.1	<i>Compressive Fresnel Holography by Undersampling the Hologram Plane</i>	85
4.4.2	<i>Compressive Digital Holography for Reconstruction of an Object Set Behind an Opaque Medium</i>	89
4.4.3	<i>Reconstruction of 3D Tomograms from a 2D Hologram</i>	90
4.5	Conclusion	96
	Acknowledgments	97
	References	97
<b>5</b>	<b>Dispersion Compensation in Holograms Reconstructed by Femtosecond Light Pulses</b>	<b>101</b>
	<i>Omel Mendoza-Yero, Jorge Pérez-Vizcaíno, Lluís Martínez-León, Gladys Mínguez-Vega, Vicent Climent, Jesús Lancis and Pedro Andrés</i>	
5.1	Introduction	101
5.2	Fundamental Features of the DCM	102
5.2.1	<i>Theory of Propagation of Diffracted Femtosecond Pulses</i>	103
5.2.2	<i>Second Order Analysis</i>	104
5.2.3	<i>Conventional Refractive Lens System</i>	105
5.2.4	<i>The Dispersion Compensation Module</i>	107
5.2.5	<i>Comparative Numerical Simulations</i>	108
5.2.6	<i>Experimental Results</i>	109
5.3	Holographic Applications of the DCM with Ultrafast Light Pulses	115
5.3.1	<i>Single Shot Second Harmonic Signals</i>	115
5.3.2	<i>Wide-Field Fluorescence Signals in Two-Photon Microscopy</i>	116
5.3.3	<i>High Speed Parallel Micromachining</i>	119
5.4	Conclusion	122
	Acknowledgments	122
	References	122

## Part II BIOMEDICAL APPLICATIONS AND MICROSCOPY

<b>6</b>	<b>Advanced Digital Holographic Microscopy for Life Science Applications</b>	<b>129</b>
	<i>Frank Dubois, Ahmed El Mallahi, Christophe Minetti and Catherine Yourassowsky</i>	
6.1	Introduction	129
6.2	DHM Configurations	130
6.2.1	<i>Phase Stepper DHM</i>	130
6.2.2	<i>Fast Off-Axis DHM</i>	130
6.2.3	<i>Color DHM</i>	132
6.3	Automated 3D Holographic Analysis	135
6.3.1	<i>Extraction of the Full Interferometric Information</i>	135
6.3.2	<i>Automated 3D Detection of Organisms</i>	135

6.4	Applications	139
6.4.1	<i>Holographic Classification of Micro-Organisms</i>	141
6.4.2	<i>Dynamics of Red Blood Cells (RBCs)</i>	145
6.5	Conclusion	148
	Acknowledgments	149
	References	149
<b>7</b>	<b>Programmable Microscopy</b>	<b>153</b>
	<i>Tobias Haist, Malte Hasler, Wolfgang Osten and Michal Baranek</i>	
7.1	Introduction	153
7.2	Optical Design Considerations and Some Typical Setups	154
7.3	Liquid Crystal Spatial Light Modulator	158
7.4	Aberration Correction	160
7.4.1	<i>Isoplanatic Case</i>	160
7.4.2	<i>Field-Dependent Aberrations</i>	162
7.4.3	<i>Defocusing</i>	163
7.5	Phase Contrast Imaging	163
7.5.1	<i>Dark Field</i>	164
7.5.2	<i>Zernike Phase Contrast</i>	164
7.5.3	<i>Interference Contrast</i>	165
7.5.4	<i>Combining Different Phase Contrast Images</i>	167
7.6	Stereo Microscopy	168
7.7	Conclusion	169
	References	170
<b>8</b>	<b>Holographic Three-Dimensional Measurement of an Optically Trapped Nanoparticle</b>	<b>175</b>
	<i>Yoshio Hayasaki</i>	
8.1	Introduction	175
8.2	Experimental Setup	177
8.2.1	<i>Optical Tweezers System</i>	177
8.2.2	<i>In-Line Digital Holographic Microscope</i>	177
8.3	Experimental Results of 3D Position Measurement of Nanoparticles	182
8.3.1	<i>A 200 nm Polystyrene Particle Fixed on a Glass Substrate</i>	182
8.3.2	<i>Axial Step in 3D Sub-Pixel Estimation</i>	183
8.3.3	<i>Brownian Motion of a 200 nm Polystyrene Particle Held in Optical Tweezers</i>	184
8.3.4	<i>Brownian Motion of a 60 nm Gold Nanoparticle Held in Optical Tweezers</i>	186
8.4	Twilight Field Technique for Holographic Position Detection of Nanoparticles	188
8.4.1	<i>Twilight Field Optical Microscope</i>	188
8.4.2	<i>Low-Coherence, In-Line Digital Holographic Microscope with the LFAF</i>	189
8.4.3	<i>Improvement of Interference Fringes of a 100 nm Polystyrene Nanoparticle</i>	190



8.5	Conclusion	191
	References	192
<b>9</b>	<b>Digital Holographic Microscopy: A New Imaging Technique to Quantitatively Explore Cell Dynamics with Nanometer Sensitivity</b>	<b>197</b>
	<i>Pierre Marquet and Christian Depeursinge</i>	
9.1	Chapter Overview	197
9.2	Introduction	198
9.3	Holographic Techniques	200
	9.3.1 Classical Holography	200
	9.3.2 From Classical to Digital Holography	200
	9.3.3 Digital Holography Methods	201
	9.3.4 Digital Holographic Microscopy	202
9.4	Cell Imaging with Digital Holographic Quantitative Phase Microscopy	206
	9.4.1 Cell Counting, Recognition, Classification, and Analysis	206
	9.4.2 Dry Mass, Cell Growth, and Cell Cycle	207
	9.4.3 Cell Membrane Fluctuations and Biomechanical Properties	208
	9.4.4 Absolute Cell Volume and Transmembrane Water Movements	208
	9.4.5 Exploration of Neuronal Cell Dynamics	210
9.5	Future Issues	213
	Acknowledgments	214
	References	214
<b>10</b>	<b>Super Resolved Holographic Configurations</b>	<b>225</b>
	<i>Amihai Meiri, Eran Gur, Javier Garcia, Vicente Micó, Bahram Javidi and Zeev Zalevsky</i>	
10.1	Introduction	225
10.2	Digital Holography	226
10.3	Metal Nanoparticles	227
10.4	Resolution Enhancement in Digital Holography	229
10.5	Field of View Enhancement in Digital Holography	231
10.6	Eliminating the DC Term and the Twin Images	233
10.7	Additional Applications	235
	References	238
<b>Part III MULTI-DIMENSIONAL IMAGING AND DISPLAY</b>		
<b>11</b>	<b>Three-Dimensional Integral Imaging and Display</b>	<b>243</b>
	<i>Manuel Martínez-Corral, Adrián Dorado, Anabel LLavador, Genaro Saavedra and Bahram Javidi</i>	
11.1	Introduction	243
11.2	Basic Theory	245
11.3	The Plenoptic Function	246

11.4	Methods for the Capture of the Plenoptic Field	249
	11.4.1 <i>Integral Photography</i>	249
	11.4.2 <i>The Plenoptic Camera</i>	251
11.5	Walking in Plenoptic Space	255
11.6	Reconstruction of Intensity Distribution in Different Depth Planes	257
11.7	Implementation of the Integral Imaging Display Device	261
11.8	Conclusion	262
	Acknowledgments	262
	References	262
<b>12</b>	<b>Image Formats of Various 3-D Displays</b>	<b>267</b>
	<i>Jung-Young Son, Chun-Hea Lee, Wook-Ho Son, Min-Chul Park and Bahram Javidi</i>	
12.1	Chapter Overview	267
12.2	Introduction	268
12.3	Multiplexing Schemes	269
12.4	Image Formats for 3-D Imaging	271
	12.4.1 <i>Image Formats for Multiview 3-D Imaging</i>	272
	12.4.2 <i>Image Formats for Volumetric Imaging</i>	289
	12.4.3 <i>Image Formats for Holographic Imaging</i>	291
	References	299
<b>13</b>	<b>Ray-based and Wavefront-based 3D Representations for Holographic Displays</b>	<b>303</b>
	<i>Masahiro Yamaguchi and Koki Wakunami</i>	
13.1	Introduction	303
13.2	Ray-based and Wavefront-based 3D Displays	303
13.3	Conversion between Ray-based and Wavefront 3D Representations	307
13.4	Hologram Printer Based on a Full-Parallax Holographic Stereogram	308
	13.4.1 <i>Holographic 3D Printer</i>	308
	13.4.2 <i>Full-Parallax Holographic Stereogram</i>	308
13.5	Computational Holography Using a Ray-Sampling Plane	310
	13.5.1 <i>Computational Techniques for Electro-Holographic 3D Displays</i>	310
	13.5.2 <i>Algorithm for CGH Calculation Using a Ray-Sampling Plane</i>	311
	13.5.3 <i>Comparison with Ray-based Techniques</i>	312
	13.5.4 <i>Optical Reconstruction</i>	312
13.6	Occlusion Culling for Computational Holography Using the Ray-Sampling Plane	313
	13.6.1 <i>Algorithm for Occlusion Culling Using the Ray-Sampling Plane</i>	313
	13.6.2 <i>Experiment on Occlusion Culling Using the Ray-Sampling Plane</i>	315
13.7	Scanning Vertical Camera Array for Computational Holography	315
	13.7.1 <i>Acquisition of a High-Density Light Field</i>	315
	13.7.2 <i>Scanning Vertical Camera Array</i>	316
	13.7.3 <i>Vertical Interpolation</i>	317

13.7.4	<i>Synthesis of Ray Images</i>	318
13.7.5	<i>Experiment on Full-Parallax Image Generation</i>	320
13.8	Conclusion and Future Issues	323
	Acknowledgments	323
	References	323
<b>14</b>	<b>Rigorous Diffraction Theory for 360° Computer-Generated Holograms</b>	<b>327</b>
	<i>Toyohiko Yatagai, Yusuke Sando and Boaz Jessie Jackin</i>	
14.1	Introduction	327
14.2	Three-Dimensional Object and Its Diffracted Wavefront	328
14.2.1	<i>Diffracted Waves with Full View Angles</i>	332
14.3	Point-Spread Function Approach for Spherical Holography	333
14.3.1	<i>Spherical Object and Spherical Hologram</i>	333
14.3.2	<i>Approximation Error</i>	335
14.3.3	<i>Computer Simulation for Spherical Holography</i>	335
14.4	Rigorous Point-Spread Function Approach	336
14.4.1	<i>Numerical Computation</i>	340
14.4.2	<i>Simulation Results on Rigorous Theory</i>	342
14.4.3	<i>Verification through Comparison</i>	342
14.4.4	<i>Hologram Generation</i>	344
14.5	Conclusion	346
	References	346
<b>Part IV SPECTRAL AND POLARIMETRIC IMAGING</b>		
<b>15</b>	<b>High-Speed 3D Spectral Imaging with Stimulated Raman Scattering</b>	<b>351</b>
	<i>Yasuyuki Ozeki and Kazuyoshi Itoh</i>	
15.1	Introduction	351
15.2	Principles and Advantages of SRS Microscopy	352
15.2.1	<i>Operation Principles</i>	352
15.2.2	<i>Comparison with Previous Raman Microscopy Techniques</i>	353
15.2.3	<i>Artifacts in SRS Microscopy</i>	356
15.2.4	<i>Physical Background</i>	356
15.3	Spectral Imaging with SRS	358
15.4	High-Speed Spectral Imaging	360
15.4.1	<i>High-Speed Wavelength-Tunable Laser</i>	360
15.4.2	<i>Experimental Setup</i>	362
15.4.3	<i>Observation of Polymer Beads</i>	363
15.4.4	<i>Spectral Analysis</i>	363
15.4.5	<i>Tissue Imaging</i>	364
15.5	Summary	367
	Acknowledgments	368
	References	368

<b>16</b>	<b>Spectropolarimetric Imaging Techniques with Compressive Sensing</b>	<b>371</b>
	<i>Fernando Soldevila, Esther Irlas, Vicente Durán, Pere Clemente, Mercedes Fernández-Alonso, Enrique Tajahuerce and Jesús Lancis</i>	
16.1	Chapter Overview	371
16.2	Single-Pixel Imaging and Compressive Sensing	372
16.3	Single-Pixel Polarimetric Imaging	373
16.4	Single-Pixel Multispectral Imaging	377
16.5	Single-Pixel Spectropolarimetric Imaging	382
	16.5.1 <i>Multispectral Linear Polarimetric Camera</i>	383
	16.5.2 <i>Multispectral Full-Stokes Imaging Polarimeter</i>	384
16.6	Conclusion	388
	Acknowledgments	388
	References	388
<b>17</b>	<b>Passive Polarimetric Imaging</b>	<b>391</b>
	<i>Daniel A. LeMaster and Michael T. Eismann</i>	
17.1	Introduction	391
17.2	Representations of Polarized Light	392
	17.2.1 <i>Optical Electro-Magnetic Fields</i>	392
	17.2.2 <i>Stokes Parameters and Mueller Matrices</i>	393
	17.2.3 <i>The Poincaré Sphere</i>	396
17.3	Polarized Reflection and Emission	397
	17.3.1 <i>Reflection</i>	397
	17.3.2 <i>Emission</i>	401
17.4	Atmospheric Contributions to Polarimetric Signatures	404
	17.4.1 <i>Reflective Bands</i>	406
	17.4.2 <i>Emissive Bands</i>	410
17.5	Data Reduction Matrix Analysis of Modulated Polarimeters	411
	17.5.1 <i>Important Equations</i>	411
	17.5.2 <i>Example Stokes Polarimeters</i>	412
17.6	Fourier Domain Analysis of Modulated Polarimeters	417
	17.6.1 <i>Rotating Analyzer</i>	417
	17.6.2 <i>Microgrid Polarimeters</i>	418
	17.6.3 <i>Band-Limited Stokes Reconstruction</i>	420
17.7	Radiometric and Polarimetric Calibration	421
	17.7.1 <i>Radiometric Non-Uniformity Correction</i>	422
	17.7.2 <i>Polarimetric Calibration</i>	423
17.8	Polarimetric Target Detection	424
	References	426
<b>Index</b>		<b>429</b>

# About the Editors

**Bahram Javidi** is the Board of Trustees Distinguished Professor at University of Connecticut.



He has been recognized by nine best paper awards, and major awards from professional societies, including fellowships of IEEE, OSA, EOS, and SPIE. In 2008, he received the Fellow Award from the John Simon Guggenheim Foundation. He has written over 870 publications, which have been cited 11 000 times according to the ISI Web of Knowledge (*h index* = 55). He has received the 2008 IEEE Donald G. Fink Prize Paper Award, the 2010 George Washington University's Distinguished Alumni Scholar Award, the 2008 SPIE Technology Achievement Award, and the 2005 SPIE Dennis Gabor Award in Diffractive Wave Technologies. In 2007, the Alexander von Humboldt Foundation awarded him the Humboldt Prize for Outstanding Scientists. He

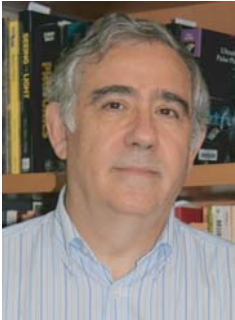
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Dr Tajahuerce's research interests lie in the areas of diffractive optics, digital holography, ultrafast optics, computational imaging, and microscopy. He has co-authored more than 90 scientific publications, and over 140 communications in conference meetings (35 of them by invitation). He is member of the SPIE, OSA, EOS, and the Spanish Optical Society (SEDO). In 2008, Dr Tajahuerce received the IEEE Donald G. Fink Prize Paper Award.

**Pedro Andrés** was born in Valencia, Spain, in 1954. He earned a PhD in physics/optics from the University of Valencia (UV) in 1983. His thesis received the 1984 Special Distinction awarded by the UV. Dr Andrés has been full a Professor of Optics since 1994 at the UV. He acted as the UV's Head of the Department of Optics from 1998–2006. He was also the Director of both the PhD and the Masters Program in the Faculty of Physics (UV) from 2008–2010.



His current research interests include static and dynamic diffractive optical elements, advanced imaging systems, microstructured fibers, temporal imaging, and ultrafast optics. He has co-authored more than 130 peer-reviewed papers. Two of these articles have received more than 200 citations each. He also supervised 13 PhD works (four of them received a Special Distinction awarded by the University of Valencia).

Currently, Professor Andrés is an expert on the Board (Branch Science) for the Evaluation of Faculty Members of Spanish Universities, President of the Iberian-American Network for Optics, Fellow of the OSA, elected member of the Board of Directors of the European Optical Society (EOS), Past-President of the Imaging Committee of the Spanish Optical Society (SEDOPTICA), and Academic Mentor of the EOS Comunidad Valenciana Student Club.

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# Preface

Imaging sciences and engineering are rapidly evolving in many ways by encompassing more sensing modalities, display media, digital domains, and consumer products. This field of research and development is frenetically active in multiple scientific, innovative disciplines including those of materials, sensors, displays, algorithms, and applications. Today, the term “optical image” refers not only to the concept of image formation and its multiple analysis, reconstruction, and visualization techniques, but also to computer vision, terahertz frequencies and electromagnetic imaging, medical imaging, algorithms for processing of images, and three-dimensional image sensing, among many others.

In the last two decades, research into advanced imaging systems has made great progress. There are many new procedures in microscopy that overcome the classical resolution limit. The field has benefited from the astonishing results of computational imaging techniques. The advances in imaging through turbid and scattering media allow the achievement of images with good resolution, either from deep layers of tissue in living beings, or the cosmos through telescopes on Earth’s surface. Optics in the life sciences incorporates new methods for non-invasive imaging of *in vivo* biological material and the tools to translate that knowledge and procedures for the study, diagnosis, and treatment of diseases. Sources of entangled photons in quantum imaging can provide high-quality images at a very low level of illumination. To all this, we must add many other rapidly evolving areas such as modern adaptive optics, imaging in nuclear medicine, optical tweezers that are opening new avenues for the study of single cells, the role of spatial light modulators in advanced imaging, and so on.

Recently, there have been rapid advances in imaging systems because of the introduction of various multi-dimensional imaging techniques, including digital holography, integral imaging, multiview, light field, multispectral imaging, polarimetric imaging, temporal multiplexing; development of new algorithms, such as those used for compressive sensing or computational imaging; and the application of new light sources, such as ultrashort lasers, laser diodes, super-continuum sources, and so on. In parallel to the development of new imaging techniques, there has been a great advance in image resolution by increasing the number of pixels of different detector arrays and reducing pixel size. It has been recognized that, in many situations, it is also very important to measure not only the spatial intensity distribution of the object, but also other useful dimensions of an image, such as spectral, polarization, optical phase, or three-dimensional structure, leading to the development of multi-dimensional imaging. As a result, there have been substantial multidisciplinary activities in the development of polarimetric cameras, multispectral sensors, holographic

techniques, three-dimensional visualization devices, and so on, integrated with special purpose algorithms to produce multi-dimensional imaging systems for a variety of applications, including medical, defense and security, robotics, education, entertainment, environment, and manufacturing.

Given the great interest in multi-dimensional imaging research, development, and education, this book, entitled *Multi-dimensional Imaging* aims to present an overview of the recent advances in the field by some of the leading researchers and educators. The book intends to educate and provide the readers with an introduction to some of the important areas in this multi-disciplinary domain. This broad overview is useful for students, engineers, and scientists who are interested in learning about the latest advances in this important field.

This book addresses a selection of important subjects in multi-dimensional imaging describing fundamentals, approaches, techniques, new developments, applications, and a relevant bibliography. It consists of 17 chapters and is divided into four parts that deal with multi-dimensional digital holographic techniques, multi-dimensional biomedical imaging and microscopy, multi-dimensional imaging and display, and spectral and polarimetric imaging. The chapters are written by some of the most prominent researchers and educators in the field.

We wish to thank the authors for their outstanding contributions, and the Wiley editors and staff for their support and assistance.

This book is dedicated to the memory of our departed friend, Dr Fumio Okano.

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*Be with those who help your being.*

*Rumi*