Automated Identification and Measurement of Cardiac Anatomy via Statistical Analysis of Medial Primitives

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A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Biomedical Engineering.

Chapel Hill

1999

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ABSTRACT

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(Under the direction of Stephen M. Pizer, Ph.D.)

Identification and measurement of objects in 3D images can be automatic, rapid and stable, based on local shape properties derived statistically from populations of medial primitives sought throughout the image space. These shape properties are measured at medial locations within the object and include scale, orientation, endness, and medial dimensionality. Medial dimensionality is a local shape property differentiating sphere, cylinder, and slab, with intermediate dimensionality also possible. Endness is a property found at the cap of a cylinder or the edge of a slab. A model of the cardiac left ventricle during systole is constructed as a large dark cylinder with an apical cap at one end, terminated at the other end by a thin bright slab-like mitral valve. Such a model, containing medial shape properties at just a few locations, along with the relative distances and orientations between them, is intuitive and robust and permits automated detection of the left ventricular axis *in vivo* using Real-Time Three Dimensional (RT3D) echocardiography. The statistical nature of these shape properties allows their extraction even in the presence of noise and permits statistical geometric measurements without exact delineation of boundaries, as demonstrated in determining the volume of balloons and of *in vivo* left ventricles in RT3D scans. The inherent high speed of the method is appropriate for real-time clinical use.

THESIS

Fully automated, rapid and robust identification and measurement of cardiac structures in 3D ultrasound images can be achieved by establishing homologies between clusters of medial primitives and the nodes in a medial model of the heart, using statistical analysis of location, scale, orientation, medial dimensionality, and endness.

"The poet's eye, in a fine frenzy rolling,
Doth glance from heaven to earth, and earth to heaven,
And as imagination bodies forth
The forms of things unknown, the poet's pen
Turns them to shapes, and gives to airy nothing
A local habitation and a name."

King Theseus, from *A Midsummer Night's Dream*,
by William Shakespeare

ACKNOWLEDGMENTS

I wish to thank Stephen Pizer for his patient teaching and constant encouragement, Olaf von Ramm and John Castelucci for including me in the adventure of 3D ultrasound, Carol Lucas for her careful reading and Ben Tsui for making me keep the application in mind. Thanks to James Coggins for adding dimensionality and Stephen Aylward for his statistical and philosophical insights. Thanks to Andrew Thall for the blues (as well as the reds and greens) and to members of the Geometry Group, IAV Seminar, and Image Lunch in the Departement of Computer Science at UNC who respectfully answered most of my stupid questions. The students at Duke contributing to the project included Richard Morris, Michael Caines, Rebekah Drezek, Roxanne Landesman, Scott Guthrie, Korin Crawford, William Portnoy, Chikai Ohazama, Visnu Pitiyanuvath, and Ge Wang. Thanks to Takahiro Shiota and Volumetrics Medical Imaging, Inc., for supplying data. Supported by a Whitaker Biomedical Engineering grant to Dr. Stetten, NSF grant CDR8622201, NIH grants 1K08HL03220, P01CA47982, and HL46242. Thanks to Nancy, Wendy, Amy, and Molly for loving me in spite of it all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AMV	Apex-to-Mitral Valve (axis)
ECG	Electrocardiogram
CO	Cardiac Output
CT	Computerized Tomography
DSR	Dynamic Spatial Reconstructor
GBPT	Gated Blood Pool Tomography
LA	Left Atrium
LV	Left Ventricle, Left Ventricular
m-reps	medial representations
MNM	medial node model
MRI	Magnetic Resonance Imaging
MUGA	Multiple Gated Acquisition
MV	Mitral Valve
RA	Right Atrium
RMS	Root Mean Squared
ROI	Region of Interest
RT3D	Real Time Three-Dimensional
RV	Right Ventricle
SPECT	Single Photon Emission Computerized Tomography
SV	Stroke Volume

LIST OF SYMBOLS

$\mathbf{x}$ or $\underline{\mathbf{x}}$	vector (in the sense of a location)
$\vec{\mathbf{c}}$	vector (in the sense of an oriented distance)
$\hat{\mathbf{v}}$	normalized vector (orientation)
$\mathbf{C}$	matrix
a	scalar
$[a,b]$	range from a to b
F	operator or function
$\mathrm{O}(n^2)$	order n^2
$\Re^m$	m - dimensional space of real numbers