Dendritic Spine Segmentation from 3D Confocal Microscopic Images

by

Hussein Sharafeddin

An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the degree of

DOCTOR OF PHILOSOPHY

Major Subject: Computer and Systems Engineering

The original of the complete thesis is on file
In the Rensselaer Polytechnic Institute Library

Examining Committee:

Badrinath Roysam, Thesis Adviser

Michael Wozny, Member

W. Randolph Franklin, Member

Deanna Thompson, Member

Rensselaer Polytechnic Institute
Troy, New York

September 2009

(For Graduation December 2009)

ABSTRACT

We present a methodology for automated segmentation of dendritic spines in three-dimensional (3-D) fluorescence microscopy images.
Dendritic spines have been linked with brain cognition and memory as well as drug interaction effects. Their significance has increased in the past decade with advances in 3-D fluorescence microscopy imaging especially for time-lapse analysis (4-D image data) in the context of pre-clinical studies. Segmenting spines is necessary to achieve accurate quantification across several snapshots.
The proposed algorithm models the dendritic shaft as a tube-like structure of varying diameter in noise studded with spines of 4 possible types, filopodia, and/or varicosities. Automated tracing of the dendritic backbone is accomplished by a previously developed algorithm that fits superellipsoids robustly and estimates the local intensity surrounding them. Once this is done, the spines are initially detected by a multi-step algorithm that first extracts the surrounding regions that deviate from the tubular geometry. A generalized likelihood ratio test is used to determine whether the initially segmented region represents a spine or just imaging noise. Because spine sizes are close to the achievable image resolution, and the fluorescent marker fluctuates in intensity, many spines appear fragmented and/or disconnected from the dendrite and thus require further analysis. For this, features such as the spine convex hull and size are quantified. Then, the spine centerline is extracted using a Fast Marching approach and a curve distance measure is used to merge candidate spine fragments.

To verify the effectiveness of the proposed methodology, a total of 14 3-D confocal microscopy images are analyzed. To obtain a broad sampling of the field, the test images were obtained from multiple laboratories, and represent multiple choices of subject animals, experimental conditions, magnifications, and imaging quality. A fully automated processing was performed without the need for user intervention. The results are shown to be superior to published state-of-the-art methods, and provide an enhancement margin over human expert detection.