

Katrin Utai

**Using real-time image processing
and active thermography with
artificial neural network modeling
for non-destructive mango quality
assessment**

UNIVERSITÄT HOHENHEIM
LEHRSTUHL FÜR AGRARTECHNIK
Agrartechnik in den Tropen und Subtropen
Prof. Dr. Joachim Müller

**Using real-time image processing and active thermography with
artificial neural network modeling for non-destructive mango
quality assessment**

Dissertation

Submitted in fulfillment of the requirements for the degree of

“Doktor der Agrarwissenschaften”

(Dr.sc.agr. / Ph.D. in Agricultural Sciences)

to the

Faculty of Agricultural Sciences

presented by

KATRIN UTAI, née SCHULZE

Germany

2018

This thesis was accepted as a doctoral dissertation in fulfillment of the requirements for the degree “Doktor der Agrarwissenschaften” (Dr.sc.agr. / Ph.D. in Agricultural Sciences) by the faculty of Agricultural Sciences at the University of Hohenheim, Stuttgart, Germany on 01.08.2017.

Date of oral examination: 01.12.2017

Examination Committee

Supervisor, Reviewer and 1 st examiner:	Prof. Dr. Joachim Müller
Co-Reviewer and 2 nd examiner:	Prof. Dr. Georg Cadisch
3 rd examiner:	Prof. Dr. Hans W. Griepentrog
Head of the Committee:	Prof. Dr. Jens Wünsche

This research was funded by the German Research Foundation (Deutsch Forschungsgemeinschaft – DFG) in the framework of the SFB 564, transfer project T4 “Multi-sensor inline system for non-invasive mango quality assessment during postharvest processing by fruit export industries in Thailand”.

Schriftenreihe des Lehrstuhls für Agrartechnik in den Tropen und
Subtropen der Universität Hohenheim
herausgegeben von Prof. Dr. Joachim Müller

Band 15/2018

Katrin Utai

**Using real-time image processing and active
thermography with artificial neural network modeling
for non-destructive mango quality assessment**

D 100 (Diss. Universität Hohenheim)

Shaker Verlag
Aachen 2018

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Hohenheim, Univ., Diss., 2017

Copyright Shaker Verlag 2018

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

Printed in Germany.

ISBN 978-3-8440-6224-3

ISSN 1867-4631

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen

Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9

Internet: www.shaker.de • e-mail: info@shaker.de

Acknowledgements

This thesis represents not only my work. It is also the result of work by many people at University of Hohenheim, Silpakorn University, Chiang Mai University and Mae Jo University and also extramural from dozens of remarkable individuals who contributed in many ways to the successful completion of this work and whom I wish to thank in the following lines

First and foremost, I am very grateful to my doctoral advisor, Prof. Dr. Joachim Müller, for supervision, support, and suggestions during the study. I am also grateful for the guidance, valuable help and constructive criticism of my supervisor, Dr. Marcus Nagle, my co-reviewer Prof. Dr. Georg Cadisch and additional examiner Prof. Dr. Hans W. Griepentrog. I also want to thank all my colleagues at the Institute of Agricultural Engineering, Tropics and Subtropics Group, at the University of Hohenheim for their pleasant cooperation and assistance during my stay at the Institute and Dr. Wolfram Spreer for his help during the years in Thailand.

Special thanks to the team of the Department of Food Technology, Silpakorn University: to Asst. Prof. Dr. Busarakorn Mahayothee, who has welcomed me to the Department and has been a source of energy ever since and to Parika Rungpichayapichet for the local advisory during the conduct of the experiments. Thanks to Asst. Prof. Jaturapatr Varith, Faculty of Engineering and Agro-Industry, Mae Jo University for allowing me to use the laboratory and who gave very helpful comments which are implemented in this work. Further thanks to Dr. Korawan Sringarm, Chiang Mai University, for allowing me to use laboratory facilities.

Thank you, Eric Verner and Vipul Lugade for teaching me so much about programming and also thank you for the professionalism needed when creating new things.

This work shall be dedicated to honor late Mr. Paichayon Uathaveekul and I would like to extend my gratitude to the whole staff of Swift Co., Ltd., Thailand for their support.

The financial support of the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG) is gratefully acknowledged. This study was funded in the framework of the project “Multi-sensor inline system for non-invasive mango quality assessment during postharvest processing by fruit export industries in Thailand” (SFB 564, T4).

Finally, I wish to thank my friends in Germany and in Thailand for their warm friendship, support and comfort. I am grateful to my beloved family in Germany for their love and support. I am deeply grateful to my dear husband Jirayu for his love, patience and understanding.

Hohenheim / September, 2018

Katrin Utai

Table of Contents

Tables	iv
Figures	v
Nomenclature.....	viii
1 General Introduction.....	1
1.1 Background.....	1
1.2 Objectives and structure of this work	2
1.3 Integration of the different components	5
1.4 References.....	5
2 Development and assessment of different modeling approaches for size-mass estimation of mango fruits (<i>Mangifera indica</i> L., cv. ‘Nam Dokmai’).....	8
2.1 Abstract.....	8
2.2 Introduction.....	9
2.3 Materials and Methods	12
2.3.1 Mango samples	12
2.3.2 Development of a simple linear regression model	13
2.3.3 Development of a multiple linear regression model.....	14
2.3.4 Development of artificial neural network model.....	14
2.3.5 Assessment of model performance.....	18
2.4 Results and Discussion	20
2.4.1 Description of data sets	20
2.4.2 Model performance.....	23
2.5 Conclusions.....	29
2.6 Acknowledgements.....	30
2.7 References.....	30
3 Mass estimation of mango fruits (<i>Mangifera indica</i> L., cv. ‘Nam Dokmai’) by linking image processing and artificial neural network.....	35
3.1 Abstract.....	35
3.2 Introduction.....	36
3.3 Materials and Methods	40
3.3.1 Sample size.....	40
3.3.2 Image processing	40
3.3.3 Setup for image acquisition	42
3.3.4 Image transformation.....	42
3.3.5 Image analysis	44
3.3.6 Artificial neural network model for mass estimation	46
3.3.7 Assessment of model performance.....	47
3.4 Results and Discussion	49

3.4.1	Description of data set.....	49
3.4.2	Training performance	50
3.4.3	Model performance assessment.....	52
3.5	Conclusions.....	56
3.6	Acknowledgements.....	57
3.7	References.....	57
4	Nondestructive detection of unapparent bruises in mango fruit by pulsed-phase thermography - Part I: functional demonstration.....	62
4.1	Abstract.....	62
4.2	Introduction.....	62
4.3	Materials and Methods	65
4.3.1	Mango samples.....	65
4.3.2	Thermodynamics of fruit tissue.....	65
4.3.3	Experimental setup for heat excitation and data acquisition	68
4.3.4	Detection of bruises from temperature data	71
4.3.5	Detection of bruises from phase data	72
4.4	Results and Discussion	76
4.4.1	Defect detection from temperature data in time domain	79
4.4.2	Defect detection from phase data in frequency domain	81
4.5	Conclusions.....	83
4.6	Acknowledgements.....	83
4.7	References.....	84
5	Nondestructive detection of unapparent bruises in mango fruit by pulsed-phase thermography - Part II: damage quantification.....	87
5.1	Abstract.....	87
5.2	Introduction.....	87
5.3	Materials and Methods	88
5.3.1	Material and experimental setup.....	88
5.3.2	Manual measurement of bruise depth.....	89
5.3.3	Estimation of bruise depth by pulsed-phase thermography	89
5.3.4	Statistical model	92
5.4	Results and Discussion	93
5.4.1	Depth determination	93
5.4.2	Disturbances from measurement environment.....	96
5.4.3	Performances of depth estimation	97
5.5	Conclusions.....	99
5.6	Acknowledgements.....	100
5.7	References.....	100
6	General Discussion	102
6.1	Future prospects.....	105
6.2	References.....	106

7 Summary 108

8 Zusammenfassung 111