Universiteit
Leiden
The Netherlands

Deep learning for online adaptive radiotherapy

Elmahdy, M.S.E.

Citation
Elmahdy, M. S. E. (2022, March 15). *Deep learning for online adaptive radiotherapy*. Retrieved from https://hdl.handle.net/1887/3278960

Version:	Publisher's Version
License:	Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden
Downloaded from:	https://hdl.handle.net/1887/3278960

Note: To cite this publication please use the final published version (if applicable).

Colophon

About the cover: The cover is a symbolic representation of a deformation grid overlaid on a coronal plane of a human body while being irradiated.

Deep Learning for Online Adaptive Radiotherapy
Mohamed S. Elmahdy

ISBN: 978-94-92597-93-9
Thesis layout & cover designed by Mohamed S. Elmahdy
Printed by Boekendeal

© 2022 Mohamed S. Elmahdy, Leiden, the Netherlands
All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the copyright owner.

Deep Learning for Online Adaptive Radiotherapy

Proefschrift

ter verkrijging van
de graad van doctor aan de Universiteit Leiden,
op gezag van rector magnificus prof.dr.ir. H. Bijl,
volgens besluit van het college voor promoties
te verdedigen op dinsdag 15 maart 2022
klokke 15.00 uur.

door

Mohamed Said Elbially Elmahdy
geboren te Caïro, Egypte in 1991

Promotores:	Prof. dr. U. A. van der Heide Prof. dr. ir. B. P. F. Lelieveldt
Co-promotor:	Dr. ir. M. Staring
Leden promotiecommissie:	Prof. dr. C. Rasch Prof. dr. M. J. P. van Osch Prof. dr. J. P. W. Pluim *Technical University Eindhoven* Prof. dr. I. Isgum *University of Amsterdam*

The research in this thesis was performed at the Division of Image Processing (LKEB), Department of Radiology of Leiden University Medical Center, The Netherlands.

Financial support for the publication of this thesis was kindly provided by:
LKEB,
Library of Leiden University
Bonitus Stichting,

Contents

Contents **i**

1 Introduction **1**
1.1 Automatic delineation in adaptive radiotherapy 1
1.2 Image registration in radiotherapy 2
1.3 Joint registration and segmentation 4
1.4 Accelerating MR acquisition for adaptive radiotherapy 4
1.5 Outline of the thesis 5

2 Robust Contour Propagation Using Deep Learning and Image Registration for Online Adaptive Proton Therapy of Prostate Cancer **9**
2.1 Introduction 11
2.2 Methods 12
2.2.1 Bladder segmentation using deep learning 13
2.2.2 Gas pocket detection and inpainting 14
2.2.3 Contrast enhancement 15
2.2.4 Image registration 16
2.3 Experiments and results 17
2.3.1 Dataset 17
2.3.2 Evaluation measures 18
2.3.3 Network training and performance 19
2.3.4 Parameter optimization and preprocessing analysis 20
2.3.5 Registration performance 22
2.3.6 Dosimetric performance 24
2.4 Discussion 25
2.5 Conclusion 31
2.6 Acknowledgements 31

3 Patient Specific Automatic Segmentation of Prostate and Organs-at-Risk for Adaptive Radiotherapy **33**

3.1 Introduction . . . 35
3.2 Materials and methods . . . 36
3.2.1 Dataset . . . 36
3.2.2 Baseline segmentation CNN model . . . 36
3.2.3 Patient-specific daily model adaptation . . . 36
3.3 Experiments and results . . . 37
3.3.1 Evaluation measures and implementation . . . 37
3.3.2 Results . . . 38
3.4 Discussion and conclusion . . . 40

4 Adversarial Optimization for Joint Registration and Segmentation in Prostate CT Radiotherapy 41
4.1 Introduction . . . 43
4.2 Methods . . . 44
4.2.1 Adversarial training . . . 44
4.2.2 Network architectures . . . 45
4.3 Experiments and results . . . 46
4.3.1 Dataset, evaluation criteria and implementation details . . . 46
4.3.2 Experiments and results . . . 47
4.4 Discussion and conclusion . . . 49

5 Joint Registration and Segmentation via Multi-Task Learning for Adaptive Radiotherapy of Prostate Cancer 51
5.1 Introduction . . . 53
5.1.1 Related work . . . 54
5.2 Methods . . . 56
5.2.1 Base network architecture . . . 56
5.2.2 Single task learning . . . 57
5.2.3 Multi task learning . . . 58
5.2.4 Loss weighting . . . 60
5.3 Datasets, implementation, and evaluation . . . 61
5.3.1 Datasets . . . 61
5.3.2 Implementation and training details . . . 62
5.3.3 Evaluation metrics . . . 62
5.4 Experiments and results . . . 64
5.4.1 Bending energy weight . . . 64
5.4.2 Optimization of the networks inputs . . . 64
5.4.3 Optimization of loss weighting strategy . . . 67
5.4.4 Analysis of cross-stitch units . . . 68

5.4.5 Effect of the bladder filling . . . 68
5.4.6 Evaluation of the quality of the DVF . . . 69
5.4.7 Comparison against the state-of-the-art . . . 69
5.5 Discussion . . . 71
5.6 Conclusion . . . 75
5.7 Acknowledgment . . . 75

6 An Adaptive Intelligence Algorithm for Undersampled Knee MRI Reconstruction 77
6.1 Introduction . . . 79
6.2 FastMRI challenge . . . 82
6.2.1 Dataset . . . 82
6.2.2 Quantitative evaluation . . . 83
6.2.3 Radiological evaluation on the challenge dataset . . . 84
6.3 Methods . . . 84
6.3.1 ISTA background . . . 84
6.3.2 ISTA-Net . . . 85
6.3.3 Adaptive-CS-Network . . . 86
6.3.4 Final design . . . 87
6.3.5 Network training and implementation details . . . 88
6.4 Experiments and results: Model optimization . . . 89
6.4.1 Number of blocks . . . 89
6.4.2 Loss functions . . . 90
6.4.3 Multi-slice network . . . 91
6.4.4 Optimizer . . . 92
6.4.5 Adaptive-CS-Net vs ISTA-Net$^+$ . . . 93
6.4.6 Soft priors . . . 94
6.5 Adaptive-CS-NET: Submitted model . . . 95
6.6 Discussion . . . 96
6.7 Conclusion . . . 98
6.8 Acknowledgements . . . 99

7 Summary and Future Work 101
7.1 Summary . . . 101
7.2 Discussion and future work . . . 104
7.3 General conclusions . . . 106

Samenvatting en toekomstig werk 107

Bibliography 115

Publications **135**

Acknowledgements **137**

Curriculum Vitae **139**