Maastricht University

Machine learning for breast cancer diagnosis in developing countries

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Appendix III

Valorization Addendum

In this thesis, we identified an affordable, non-invasive, and portable breast thermography imaging modality for breast cancer detection in developing countries and proposed a computer aided diagnosis (CAD) solution to ease the imaging protocol, automate the interpretation and assist clinicians in breast cancer detection. The individual modules of the CAD solution were validated and compared with the contemporary machine learning solutions that existed in the literature to evaluate the effectiveness of the proposed approaches, as discussed in the chapters of this thesis. In this Appendix, we will briefly describe the transformation of the work discussed in this thesis into commercial entities in the form of patents, startup incorporation and social impact.

Patents

The novelty of the proposed approaches in this thesis has led to 5 patent grants as listed below.

a. The heuristic based segmentation approach proposed in **Chapter 3** was granted as a patent (No: 10,068,330) by the United States Patent and Trademark Office (USPTO) in 2018.
b. The vessel segmentation algorithm proposed in **Chapter 5** was granted as a patent (No: 10,198,670) by USPTO in 2019.
c. The features for malignancy characterization proposed in **Chapter 7** are separated into two inventions and are granted by USPTO with patent numbers US 9,865,052 and US 10,307,141 in 2018.
d. Hormonal status prediction proposed in **Chapter 8** is also granted as patent by USPTO (No: 10,368,846) in 2019.

NIRAMAI Health Analytix Private Limited

NIRAMAI (**N**on-**I**nvasive **R**isk **A**ssessment with **MA**chine **I**ntelligence) is a healthcare startup with headquarters in Bengaluru, India, that focuses on improving breast cancer diagnosis in developing countries like India. Niramai has built a cloud software to automatically analyze and interpret the breast thermal images. Niramai's cloud software is used in more than 30 different locations across India. They also conduct rural camps to provide cancer care in rural regions of India.

The techniques proposed in this thesis were implemented in Niramai's cloud software to improve the breast thermal image capture and the diagnosis. The tagging or view labeling architecture discussed in **Chapter 4** is used in the cloud software to alert the technicians in case of improper manual labeling of images. On the other hand, the segmentation approach proposed in **Chapter 4** is used to estimate the breast region in the thermal images. The software further allows the human expert to adjust the predicted region for accurate analysis in case of any errors. Since the proposed predicted

segmentation was observed to be close to a human expert, it helps in decreasing the overall image analysis time for the cloud software. **Chapters 5-7** are used in the Niramai solution to automatically generate the final report of the subject from the thermal images. This report consists of risk scores and parameters describing the tumor and vascularity in the breast region. The neural network-based risk estimation approach proposed in **Chapter 9** was released by Niramai to the public through https://www.niramai.org in 2018. The same service is also available from their relationship with JIO mobile app under health services. This service generates a risk score from breast cancer risk factors and helps in educating women about their risk of breast cancer.

Social Impact

Niramai has conducted over 30000 screenings in India with the help of low skilled technicians using the proposed solution in this thesis. This shows the effectiveness of the proposed state-of-the-art solutions in real practice. The large-scale screenings could also improve the accessibility of breast cancer care to women. Niramai is currently conducting multi-site clinical studies to validate the diagnostic and the screening usage of the overall cloud solution. Overall, this solution has an ability to reach masses in developing countries and might help in reducing the current high mortality rates through early detection in developing and undeveloped countries in the coming years.