The accuracy and reliability of statistical classification in imaging applications

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Abstract

The validity of image segmentation is an important issue in image processing because it has a direct impact on surgical planning. We examined classification accuracy in imaging analysis based on three two-sample validation metrics against the estimated composite latent gold standard, which was derived from several experts’ manual segmentations by an expectation-maximization (EM) algorithm called STAPLE. The distribution functions of the tumor and control pixel data were parametrically assumed to be a mixture of two beta distributions with different shape parameters. We estimated the corresponding receiver operating characteristic (ROC) curve, Dice similarity coefficient, and mutual information, over all possible decision thresholds. Based on each validation metric, an optimal threshold was then computed via maximization. We illustrated these methods using magnetic resonance (MR) imaging data on three radiologic examples: (1) accuracy of brain tumor segmentation, (2) functional imaging for detection of brain activation, and (3) hidden gold standard in prostate peripheral zone segmentation for brachytherapy. The performances of these validation metrics were investigated via Monte-Carlo simulation. Extensions of incorporating spatial correlation structures were briefly considered under a Markov random fields model.

Key Words: Sensitivity, Specificity, Receiver operating characteristic (ROC) curve, Dice similarity coefficient, Mutual information, Expectation maximization (EM) algorithm, magnetic resonance (MR) imaging, Functional MR (fMRI).

See: Kelly’s Brief Bio on the Next Page.
Biographical Information

Dr. Kelly H. Zou is an Associate Professor in Radiology and Health Care Policy at Harvard Medical School and its affiliated Brigham and Women's Hospital. She received her B.A. (Summa Cum Laude) in Mathematics and Physics from Chaminade University of Honolulu in 1992, M.A. and Ph.D. in Statistics (with concentration in Biostatistics) from the University of Rochester in 1994 and 1997, respectively. She completed a joint postdoctoral fellowship in Biostatistics and Radiology at Harvard Medical School and Brigham and Women's Hospital in 1999. Since then she's been on the faculty of Harvard Medical School.

Dr. Zou's statistical methodological and applied work has been devoted to health care policy and cancer imaging research. Currently she’s the Principal Investigator of Grant NIHR01-LM007861, entitled “Improved Tumor Resection in Image-Guided Neurosurgery.”

Much of her methodology work involves statistical problems associated with receiver operating characteristic (ROC) curve analysis, which is useful for evaluating and comparing the diagnostic accuracies of diagnostic markers or imaging modalities. Her work on ROC analysis has led her to be the recipient of the Stauffer Award for the best article published in Academic Radiology. She was also the recipient of the Travel Stipend Award from the Society of Health Services Research in Radiology and Reviewer with Special Distinction Award for Radiology. The second area of Dr. Zou's original research on health care policy is on the design of multi-center health quality of care studies. The third area of Dr. Zou's original research is on the development of improved methods for estimating the reliability of a measurement using an intra-class correlation coefficient or a kappa statistic.

In the area of applied research, Dr. Zou is a referee for a number of professional journals and has been serving on the Committee of Applied Statisticians, American Statistical Association. She has also been an investigator, statistician, and author on a number of collaborative medical research projects. For example, she was a statistician in two multi-institution Radiologic Diagnostic Oncology Group (RDOG) studies (funded by NCI).

Dr. Zou's statistical research in imaging analysis (funded by NIA) has focused on the evaluation of image-guided minimum invasive Brachytherapy for prostate cancer and cryo therapy for liver cancer. Dr. Zou's roles in these projects include study designs, technology assessment and analysis. She has also been the biostatistician in the Department of Radiology, Brigham and Women's Hospital and offers consultations on numerous funded clinical studies. Finally, another focus area of Dr. Zou's applied research is on functional MR imaging (fMRI) as a statistician of a national multi-center study sponsored by Biomedical Informatical research network (BIRN).

Dr. Zou's teaching activities included development and instruction in several courses on statistical methods for clinical research and ROC analysis for the Brigham and Women's Hospital Radiology residents, fellows and faculty members. She has also been a course developer and instructor of invited statistical seminars locally and nationally.