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*Title of the PhD thesis: Modeling and imaging of the vocal fold vibration for voice health*

Popular science summary of the PhD thesis in Danish

Medicin sigter efter at give forklaringer på årsager og konsekvenser af sundhed og sygdomme baseret på empiriske beviser, hvilket typisk involverer detaljerede undersøgelser af kroppens indre. Anskaffelsen af disse empiriske beviser ville kræve undersøgelse af anatomien fx ved at dissekere lig eller endda ved at undersøge levende væsener ved vivisektion. Disse videnskabelige procedurer har dog åbenlyse praktiske og etiske begrænsninger, hvilket motiverer brugen af alternative metoder fra videnskaben og de teknologiske fremskridt. I studiet af det menneskelige fonatoriske system er det nu muligt at fange stemmebåndenes svingninger i detaljer med en teknologi kaldet laryngeal højhastighedsvideo-endoskopi. Der er dog nogle vævsrelaterede medicinske hypotetiske skader, der ikke kan testet med denne form for observationer. Denne afhandling er derfor et analytisk studie af problemet om estimering af stemmebånds funktion, hvilket ikke er synlig for det blotte øje (inversionsproblem). Studiet er lavet ud fra kvantitative analyser af laryngeal højhastighedsvideo-endoskopi (data). Derudover kan mere viden om stemmebåndenes mekanismer forbedre de fremtidige estimater. Problemet er delt i tre under-problemer, der alle omhandler de biomekaniske modeller af stemmebåndene. Specifikt omhandler de den kollision som er relateret til hypotesen for skader, metoder til at opnå laryngeal dataopsamling og en statistisk inversion, hvilket giver usikre beregninger og informationer for de estimater, der er relevante for en klinisk beslutningsproces.

Scientific summary of the PhD thesis in English

Identification of abnormalities on the vocal fold by means of different diagnostic methods is a key step to determine the cause or causes of a voice disorder, and subsequently give an adequate treatment. To this end, clinical investigations benefit from accurate mathematical models for prediction, analysis and inference. This thesis deals with biomechanical models of the vocal fold, specially of the collision, and laryngeal videoendoscopic analysis procedures suitable for the inference of the underlying vocal fold characteristics.

The first part of this research is devoted to frictionless contact modeling during asymmetric vocal fold vibration. The prediction problem is numerically addressed with a self-sustained three-dimensional finite element model of the vocal fold with position-based contact constraints. A novel contact detection mechanism is shown to successfully detect collision in asymmetric oscillations. Optimization procedures for constraint enforcement are studied to improve the accuracy of the predictions as an alternative to classical spring-like contact forces. The second part of this research investigates a non-invasive procedure to quantitatively analyze the two-dimensional vocal fold displacements captured with laryngeal high-speed videoendoscopy. A dense optical flow algorithm is adapted to the complex nature of the image sequence, and numerical errors are treated to improve the accuracy of the results. Principal components decomposition is applied to extract the underlying modes of vibration, showing different

characteristics in normal and abnormal phonation. In the last part of this thesis research, the optical flow algorithm for data acquisition as well as the biomechanical model of the vocal fold are used to formulate a nonstationary statistical inverse problem for vocal fold features estimation that accounts for the model uncertainty. An expectation-maximization algorithm for missing data is proposed to find estimates of the system's unknowns. Due to time limitations no computational results are shown and a purely theoretical discussion is presented.