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New parameters of the glottis closure analysis

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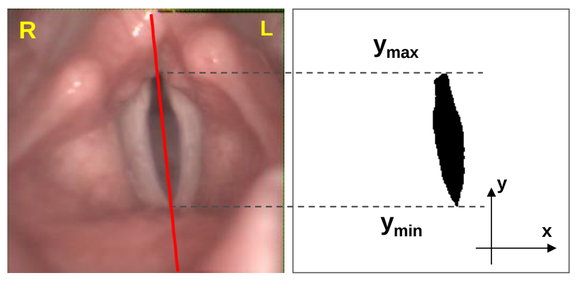
Introduction

High speed video camera (HSV) is used to examine vocal cords kinematics. The recording allows to observe slowed down movement of the vocal cords. However observation alone may not be sufficient to evaluate quality of vocal cords kinematics. Therefore we are looking for parameters which would characterize significant changes in vocal cords opening during one or more periods.
Years of experience with voice range profile analysis, multidimensional analysis and glottal closure quality analysis led us to the idea of extending the set of parameters available in commercial HSV software. The aim is to find parameters and cost functions, which would improve evaluation of quality of the vocal cords kinematics, especially early diagnosis.
In this text we discuss automatic detection of the anatomical axis of the vocal cords and selected parameters of the vocal cords kinematics derived from the axis and its normal.
Mentioned parameters are of symmetry and position of geometric center of vocal cords opening.

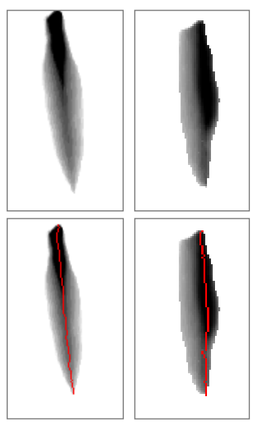
Approach and Methods

Firstly the opening is detected in frames of HSV sequence. The sequence has following parameters: 4000 fps; T_{sample} = 0,25 ms; 256 x 256 px.



Anatomical axis of vocal cords — Vocal cords opening

The parameters of the axis equation are estimated automatically. Basis of this approach is summation of the brightness values of coincidental points of each frame in the sequence followed by point filtering by averaging of the frames. The darkest points (the opening is dark) represent areas where the opening is opened for the longest time.

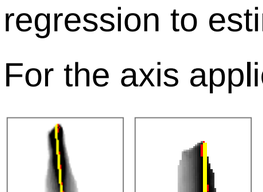


Grayscale images after addition of all frames in given sequence and application of point filtering.
(Symmetrical and asymmetrical movement)

Visualization of most frequent points of vocal cords opening per line.
(Symmetrical and asymmetrical movement)

In some cases parts of the opening may be covered (near upper and lower commissure) and the area of opening appears floating. Solution is to use statistical analysis and linear regression to estimate the anatomical axis.

For the axis applies: $a\,x + b\,y + c = 0$



$$a = \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i - n \sum_{i=1}^{n} x_i\, y_i$$

$$b = n \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i \right)^2$$

$$c = \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i\, y_i - \sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} y_i$$

The resulting estimate of the anatomical axis of the vocal cords obtained by application of linear regression and floating axis method.

Parameters

The parameters for evaluation of the vocal cord kinematics can be divided in following groups:

- parameters of individual frames
- parameters of frame sequence
  - one vocal folds oscillation
  - given number of vocal folds oscillations
- parameters of the opening between the vocal cords
  - circumference and area of the opening
  - **position of the geometric center**
  - symmetry of the vocal folds oscillation
  - roundness and compactness of the vocal cords boundaries
  - frequency analysis of the vocal cords boundaries
  - speed quotient
  - vocal cords openness quotient

Parameters of the geometric center of the opening are:

$\boldsymbol{D_x}$ … distance of the geometric center from the anatomical axis
$\boldsymbol{D_y}$ … distance of the geometric center from normal

For these parameters applies relation:

$$D_x = \frac{a\,x_C + b\,y_C + c}{\sqrt{a^2 + b^2}}, \qquad D_y = \frac{a_{norm}\,x_C + b_{norm}\,y_C + c_{norm}}{\sqrt{a_{norm}^2 + b_{norm}^2}},$$

where $x_C = \frac{1}{A_k} \sum_{x \in S_k} \sum_{y \in S_k} x$, $y_C = \frac{1}{A_k} \sum_{x \in S_k} \sum_{y \in S_k} y$

are coordinates of the geometric center of the opening.

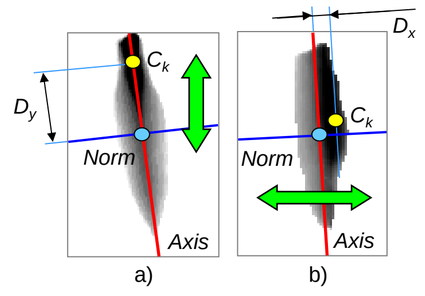
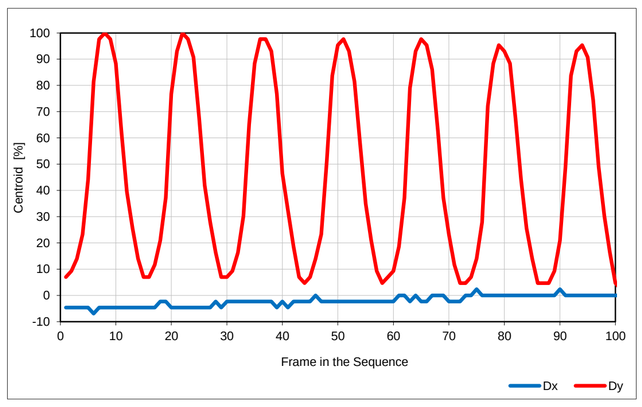
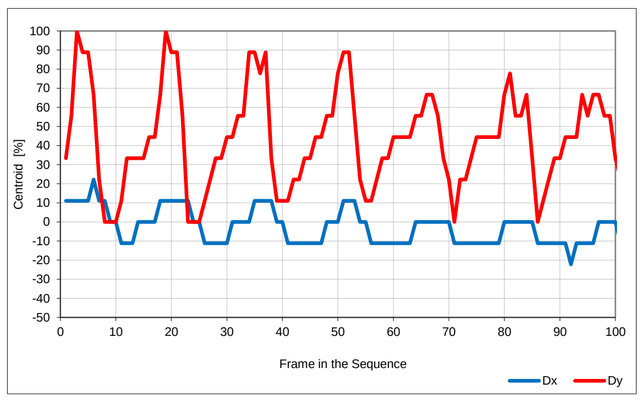


Diagram illustrates change of parameters of geometric center $\boldsymbol{D_x}$ a $\boldsymbol{D_y}$ during one vocal fold oscillation.
a) symmetrical vocal cord
b) asymmetrical vocal cord (carcinoma)



a) symmetrical vocal cord, predominant change in distance $\boldsymbol{D_y}$



b) asymmetrical vocal cord (carcinoma), significant change in distance $\boldsymbol{D_x}$

Conclusion

Observing position of geometric center allows to evaluate symmetry of vocal cords. If the vocal cords are symmetrical, the geometric center moves along the anatomical axis. However, in case of only slight asymmetry the geometric center moves in perpendicular direction as well.