Toward assessing stability and sensitivity of tongue contour metrics

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Introduction

Many metrics have been proposed and used to analyse the shape and changes in the tongue contours extracted from ultrasound images [e.g. 1, 2, 3]. While at least one analysis on the categorisation power of the metrics of some metrics exists [2], there is no stability or sensitivity analysis in the literature as far as we know. The latter types of analysis are also important because an ideal metric will change only a little for a small change in the contours (stability), and on the other hand, will show that there is change when there is relevant change (sensitivity).

To address this, we are developing methods to assess the local stability and long distance reliability of contour metrics based on simulated data. As examples, we provide preliminary analysis of Modified Curvature Index [2] and Average Nearest Neighbour Distance [1]. We analyse MCI instead of the original Curvature Index (CI) [4] because CI is not invariant against probe rotation [2] while MCI is specifically designed to be a rotation invariant version of CI.

To enable others to test metrics they are interested in we provide the simulated test data and the Python code for running the tests as part of the SATKIT package [5, 6]. The main purpose of the present study is to provide a proof-of-concept of the analysis method.

Materials and Methods

We used two example vowel contours – [æ] and [i], Figure 1, left panel – traced from Ladefoged's *Vowels and Consonants* [7]. These were sampled as if the sampling was a result of splining the contour with 42 control points based on a radial fan with the probe under the chin. The contours were perturbed at each sample point by {-2, -1, -.5, .5, 1, 2} mm to simulate small errors and variation in contour extraction. Perturbations are demonstrated in the right panel of Figure 1.

Since the Modified Curvature Index (MCI) is a shape metric, it is calculated on a single contour. Tos study its sensitivity to perturbations we calculated the logarithmic ratios of MCI of perturbed contours to MCI of the baseline contour.

In contrast, Average Nearest Neighbour Distance (ANND) is a difference metric and computed on between two contours. To simulate time-local change, we computed it between each vowel's the

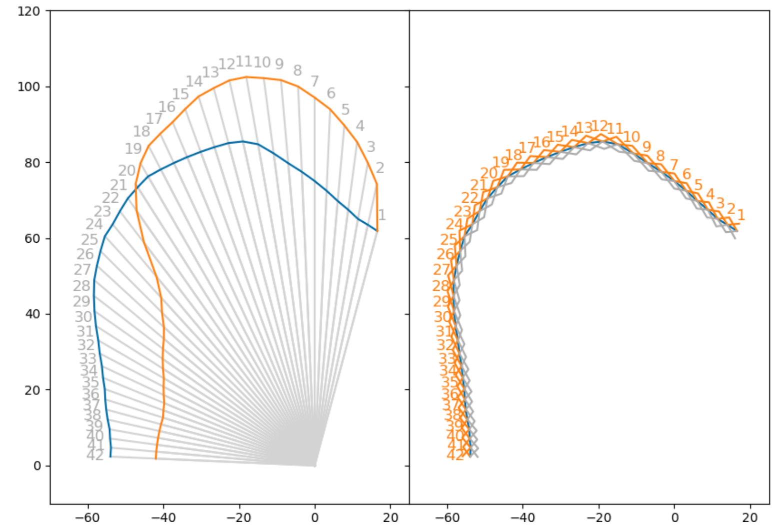

Figure 1: On the left: [æ] (in blue, lower) and [i] (in orange, higher) with sample point numbers. The grey rays originate at the mock probe position. On the right: radial perturbations of ±1mm on [æ]. Positive perturbations (away from the mock probe position) are shown in orange and negative perturbations (towards the mock probe position) are shown in light grey.

baseline and corresponding perturbed versions. To simulate a long distance context, we repeated the calculation by using one vowel as the reference while perturbing the other. ANND changes with direction of comparison, so all comparisons were run in both directions.

Results

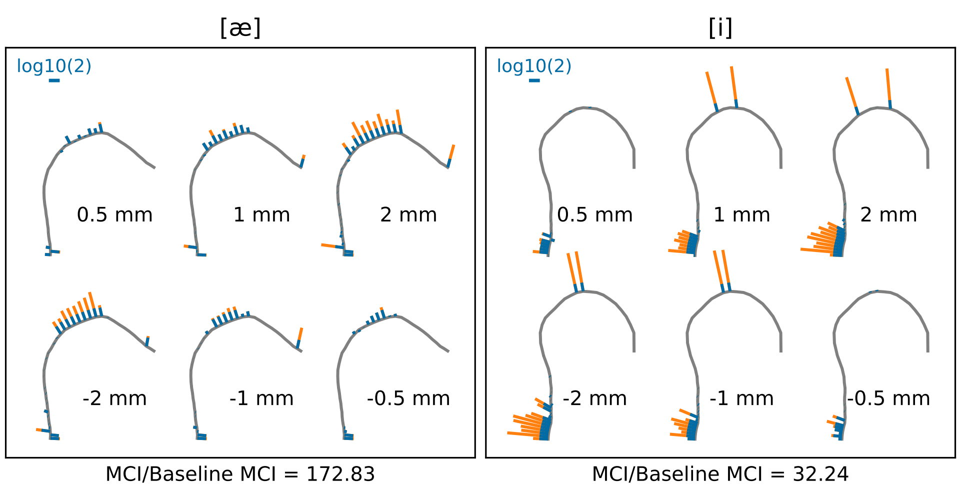

Figure 2: Perturbed MCI related to baseline MCI on a *log-scale* at the points of perturbation. Orange marks ratio > 2. The largest values of MCI([i]) $>$ baseline MCI([æ]).

Figure 2 shows that MCI is very robust against single point perturbations in some parts of the contour and oversensitive in others. This goes as far as MCI([i]) becoming over 5 times as large as baseline of [æ] when a single point is moved by 1 mm.

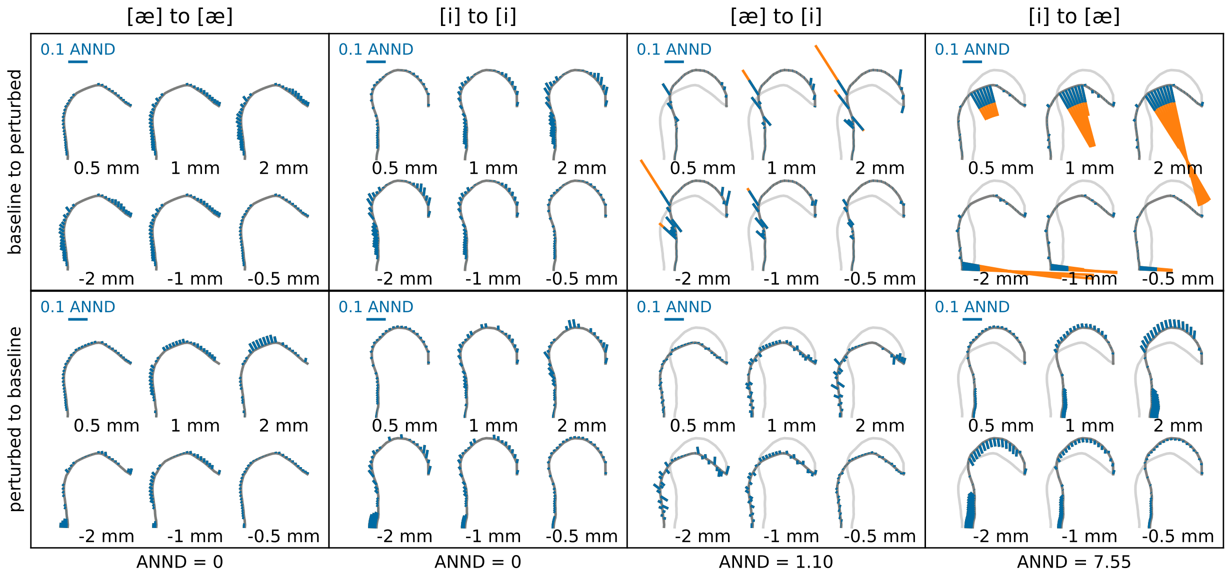

Figure 3: ANND from baseline contours to perturbed and vice versa plotted on a *linear scale* in relation to the reference values shown on the bottom. In the two columns on the right the values are displayed on the perturbed contour.

ANND is also sensitive to perturbations but very importantly the most sensitive areas change depending on which direction the comparison is in. Between baselines ANND([æ] to [i]) ≈ 1.10 versus ANND([i] to [æ]) ≈ 7.55. Largest absolute change in ANND in all comparisons was ANND([i] to 2 mm perturbed [æ]) at ≈ -0.75.

Discussion

The results show that not only does our method work, but it provides potentially interesting data. Given that the analysis has been run on single contours and even though the perturbations were done on all points, the results should not be taken as an absolute indication of typical behaviour of the metrics. For that we will need more contours, real world data, and preferably also mathematical analysis of the metrics.

Adding new contours should not be just a case of adding new static contours (which is important) but we also want to add methods for interpolating between two end-point contours to simulate analysis of a tongue moving in time, and ways of scaling the contours etc. Another aspect that needs analysis is using different numbers of sample points across a contour. Real world data should be used to see how the metrics behave with perturbations of actual data. Mathematical sensitivity analysis would provide a way of seeing how a metric *should* behave and e.g., flag up an implementation for debugging, if the implementation does not follow the theoretical sensitivity results.

As future work we are interested in doing the above, adding more metrics, simulating variation in probe position, tongue scale, linear interpolation between two tongue positions and more. The long term goal is to provide the community with an easy-to-use framework for testing old and new metrics. We welcome questions, suggestions, and general discussion to guide the next steps.

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