Vowel-Vowel production on a Distinctive Region model. A new command strategy

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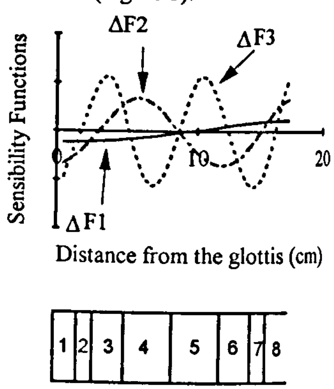
ABSTRACT

Previous studies on the distinctive region model emphasise the efficiency of the longitudinal command applied between two constriction regions to provide a quasi-rectilinear acoustic trajectory in the plane F_1-F_2 [1]. In this paper, the longitudinal command is not only applied between two constriction regions but also between a cavity and a constriction and vice versa [2]. This new command has two advantages. First, it allows to take into account the limitation of the tongue movements. Second, it allows to keep the quasi-rectilinearity acoustic property of formant trajectories.

I. DISTINCTIVE REGION MODELLING OF THE VOCAL TRACT.

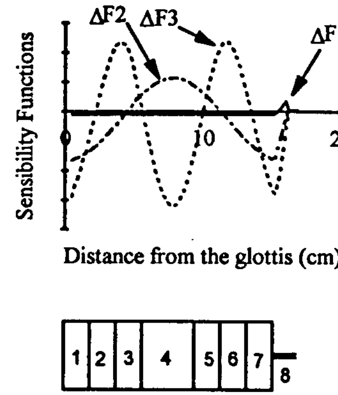
The distinctive region modelling of the vocal tract has been described according to the hypothesis that the tongue realises a succession in time domain of single constriction and it articulates according to a minimum effort concept. If the articulation targets is acoustic, then the tongue must exploit regions of articulation where the formant frequencies are the most sensitive [2]. But the tongue articulates in two configurations which have different acoustic properties. If the lips are open, the configuration is a Closed-Open Tube (COT). If the lips are nearly closed, the configuration is a Closed-Closed Tube (CCT). In order to determine the regions of the model for the two configurations, the sensitivity functions [3] corresponding to each of the three first formants were calculated for an uniform tube. The regions are obtained by dividing the tube at the zero crossings of the sensitivity functions [1]. These sensitivity functions were calculated first for the configuration COT and eight regions were obtained (Figure 1). The region R8 represents the lip aperture. The closure of this region gives rise to the configuration CCT. The sensitivity functions were also calculated for this configuration and eight regions were then obtained with different boundaries (Figure 2).



	R1	R2	R3	R4	R5	R6	R7	R8
F1	-	-	-	-	+	+	+	+
F2	-	-	+	+	-	-	+	+
F3	-	+	+	-	+	-	-	+

Figure 1. Distinctive region modelling in the configuration COT and matrix of variation of formant frequencies.

The superposition of the model with its two configurations on the vocal tract gives a physiological significance to the regions of the model (Figure 3). Four regions (R3 to R6) and five regions (R2 to R6) are considered as the tongue ones in, respectively, the configuration COT and the configuration CCT. These regions share out the tongue from the low of the pharynx up to the tongue tip.

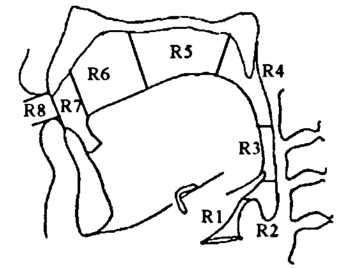


	R1	R2	R3	R4	R5	R6	R7
F1	0	0	0	0	0	0	0
F2	-	-	+	+	+	-	-
F3	-	+	+	-	+	+	-

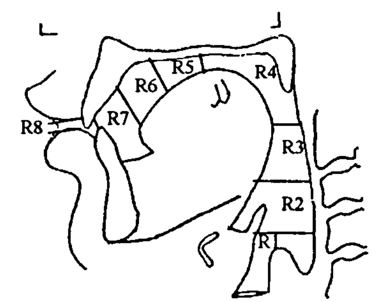
Figure 2. Distinctive region modelling in the configuration CCT and formant frequencies variation matrix.

The two configurations of the model allow to model the area function of any vowel by specifying its region and degree of constriction and its corresponding lip opening. In order to describe realistic area functions, the constraint of the constant volume of the tongue was integrated. This constraint is modelled by opposite commands on two regions linked by the acoustic synergy property. Namely, if a constriction is applied to one region among the tongue ones, a cavity is shaped on the region with which the constriction region shares the same variation of the formant frequencies by antisymetrical command.

The transition from an area function to an other is driven by a command strategy.



(a) Vocal Tract and Configuration COT



(b) Vocal Tract and Configuration CCT

Figure 3. Distinctive region modelling of the vocal tract.

II. COMMAND STRATEGY OF THE MODEL.

The command strategy elaborated for the model is built on a set of area function prototypes that differ in the region of constriction and the labial aperture state, i.e., open lips or nearly closed lips. The command strategy rules define a command, among possible ones, that minimises an acoustic criterion for every transition between two area function prototypes.

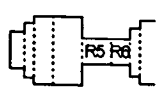
II.1. Area function prototypes.

The regions of constriction are chosen from the tongue region ones. Four area function prototypes are then obtained from the configuration COT (figure 4a) and one area function prototype is obtained from the configuration CCT (Figure 4b).

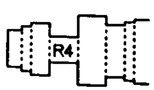
II.2. Two commands of the model.

A command of the model is described by the interpolation between two area function target parameters. If these parameters are the areas of the model regions, the interpolation gives rise to a transversal command (Figure 5a) and if these parameters describe the constriction, the interpolation gives rise to a longitudinal command (Figure 5b). This last command is obtained by the displacement of the constriction along the model.

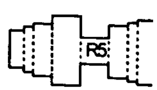
R3 and R4 (BK)
(BK -*BacK*-)



R5 and R6 (FT)
(FT -*FronT*-)

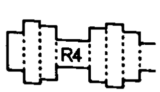


R4 (CBK)
(CBK -*Central BacK*-)



R5 (CFT)
(CFT -*Central FronT*-)

(a) Configuration COT

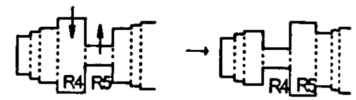


R4 (CC)

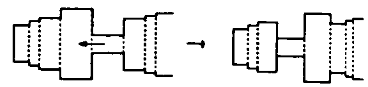
(CC - *Central Constriction*)

(b) Configuration CCT

Figure 4. Prototypes of area functions of the distinctive region model



(a) Transversal command



(b) Longitudinal command

Figure 5. Two commands of the distinctive region model.

II.3. Acoustic criterion and the primary rules of the command strategy.

The acoustic criterion is based upon an hypothesis where the best way to move from one target to another is the most rectilinear one. So the best command that is chosen to execute any transition is the one that minimises:

$$J(u) = \int_{t_0}^{t_1} (F_2(u(t), F_1) - F_{2o}(F_1))^2 \, dt$$

where u(t) is the command versus of time, $F_2(u(t), F_1)$ represents the formant trajectory on the plane F_1-F_2 obtained with such a command and $F_{2o}(F_1)$ is the straight line between the two acoustic targets on the plane F_1-F_2.

The optimal command choice for all possible transitions between area function prototypes gave rise to the primary rules which take into account no articulatory constraints.

II.4. Introduction of an articulatory constraint and the new command strategy rules.

The preceding command strategy allows the longitudinal displacement of the constriction toward or from the low region of the pharynx. This behaviour of the area function is not realistic [2]. Two possibilities of representation of the area function have been considered to include this constraint. A constriction on one region of the area function involves a cavity on another region because of the constant volume of the tongue. So an area function can be represented either by the place and the degree of the constriction and the labial aperture or by the place and the degree of the opening of the corresponding cavity and the labial aperture. The exploitation of this equivalence in the configuration COT of the model allowed to replace the longitudinal command toward or from the constriction on the low region of the pharynx (R3) by the longitudinal command toward or from the corresponding cavity region (i.e., R6) (Figure 3a). This equivalent command allows to control the low region of the pharynx by only a transversal command such as it has been noticed in the last investigations of the natural articulatory data.

The use of this equivalent command in order to take into account the articulatory constraint led to the following rules:

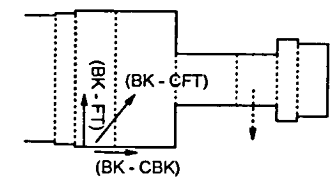
- A target region must be different from R3 that represents the low region of the pharynx.

- A target region could be either a constriction or a cavity in the two area functions that constitute the transition. So the target regions of the command can be chosen among four possible couples. This rule derives from the use of the equivalent command.

-In order to take into account the concept of minimum of effort, the target regions of the command must be consecutive.

III. DISCUSSIONS.

Figure 6 gives an example of area function transitions on the model and their corresponding tongue movements. In this command strategy, several possibilities of the tongue deformation can be proposed and be a subject of study on the natural articulatory data. But it was showed that there is an interaction between the lips motions and the tongue mechanism. So, it would be more interesting to establish and take into account this interaction [2] before studying the natural data. However, the command strategy, as described in this paper, was used with benefits and other perspectives have been proposed on the improvement of the model [2].



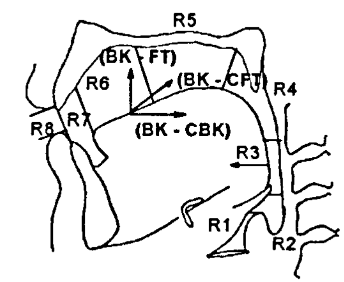


Figure 6. Examples of the tongue shaping from BK area function according to the new command strategy.

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