Sound synchronization and motion compensated reconstruction for speech Cine MRI

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Pierre-André Vuissoz[1,2], Freddy Odille[1,2], Yves Laprie[3,4], Emmanuel Vincent[3,5], and Jacques Felblinger[6,7]

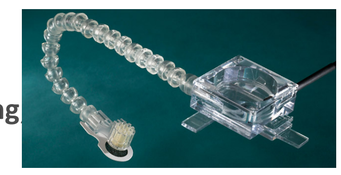
1. *Imagerie Adaptative Diagnostique et Interventionnelle, Université de Lorraine, Nancy, France,* ***2.*** *U947, INSERM, Nancy, France,* ***3.*** *LORIA, Université de Lorraine, Nancy, France,* ***4.*** *LORIA, CNRS, Nancy, France,* ***5.*** *LORIA, INRIA, Nancy, France,* ***6.*** *University Hospital Nancy, Nancy, France,* ***7.*** *CIC-IT 1433, INSERM, Nancy, France*

Purpose :

Dynamic imaging of the **vocal tract** is important for modeling speech through the acoustic-articulatory relation. The average duration of each sound is about 80 ms. Movements of each articulator, in particular the tongue, should be captured with sufficient precision.

Previous works :

- X-ray video fluoroscopy : ionizing radiation;
- Real-time MRI [1]: limited SNR and spatial resolution;
- Cine MRI with acoustic device gating [2]: needs highly reproducible motion.



This work:

- Ungated acquisition with **acoustic** device **recording**.
- **Motion-compensated** [3,4] **cine** reconstruction.

Material & Methods :

- Data acquisition :

Dynamic MRI data were acquired at 3T (Signa HDxt, GE Healthcare, Milwaukee, WI) using an ungated **balanced SSFP** sequence (one sagittal slice, 256x256 matrix, TR/TE = 3.9/1.7 ms, 5 mm slice thickness, 45° flip angle, FOV 30 cm, 65 temporal phases).

A list of 10 sentences was carefully selected for the **dynamic imaging protocol** to be short and yet yield a good coverage of the tongue movements in French language [5] : « Ma chemise est roussie », « Donne un petit coup », « Voilà des bougies », « Une réponse ambiguë », « Louis pense à ça », « Mets tes beaux habits », « Une pâte à choux », « Prête-lui seize écus », « Chevalier du gué », « Il fume son tabac » .

For each dynamic acquisition the subject was asked to **repeat** one of the 10 **sentences** until the sequence stopped. Acoustic signals were acquired using an optical microphone (FOMRI III, Optoacoustics, Yehuda Israel). The scanner's acquisition window signal was also recorded with the device to allow synchronization of MR events and acoustic signals.

- Acoustic signal processing :

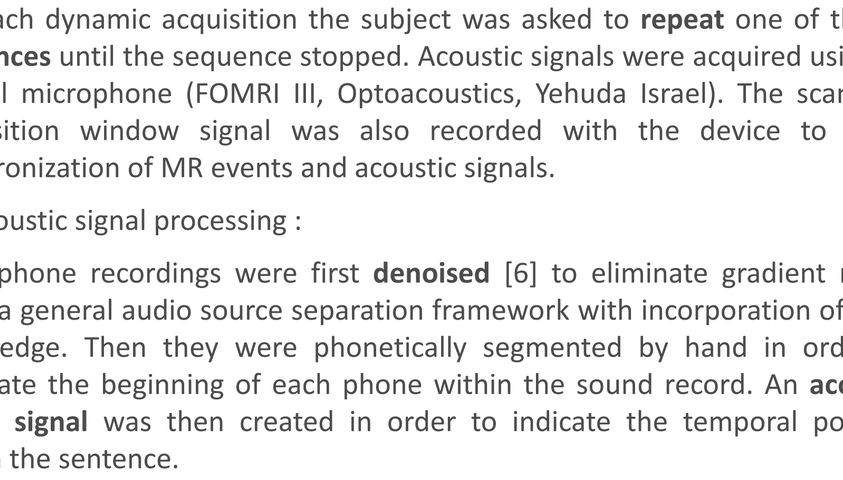
Microphone recordings were first **denoised** [6] to eliminate gradient noise, using a general audio source separation framework with incorporation of prior knowledge. Then they were phonetically segmented by hand in order to annotate the beginning of each phone within the sound record. An **acoustic phase signal** was then created in order to indicate the temporal position within the sentence.

In order to account for the variability of repeated phone timings, the phase signal was adjusted using a **piecewise linear scaling** based on the manual segmentation.

- Reconstruction :

Cine images from each template sentence were reconstructed using **cine-GRICS** [7]. Here cine-GRICS used the **acoustic phase signal** to reconstruct the images by a **motion-compensated sliding-window** approach.

The window width was 80 ms and motion correlated signals were the relative phase distance to the key frame position and the squared distance. 128 key frames were used.

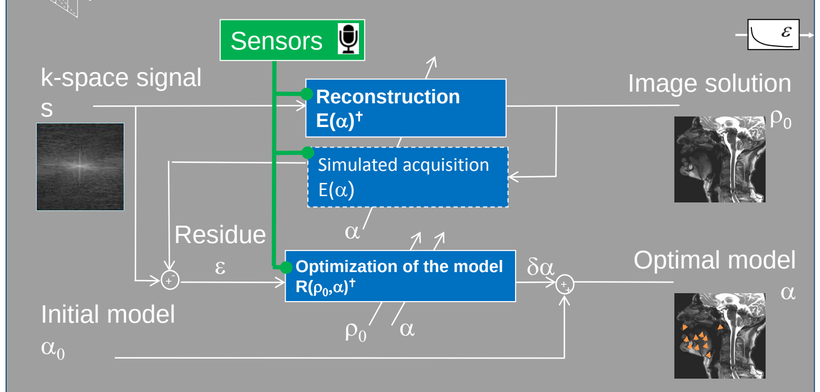


Acoustic signal processing

Constrained reconstruction

Generalized Reconstruction by Inversion of Coupled Systems (GRICS)

$$\begin{cases} s = E(\alpha)\rho_0 & \text{(reconstruction with known motion)} \\ \varepsilon = R(\rho_0, \alpha)\delta\alpha & \text{(optimisation of motion model)} \end{cases}$$



Motion model constrained by the temporal position in the sentence :

$$U_{\lambda,\tau}(r,t) = \sum_k \alpha_{k,\lambda,\tau}(r) S_k(t)$$

Results :

- In Figure 1 two images of the subject pronouncing "Voilà des bougies" show the **absence** of motion blurring or **artifact** in the reconstructed cine loop.
- In Figure 2 the distances between the tongue dorsum and the hard palate and between the tongue back and the pharyngeal wall are shown along with the template sentence signal.

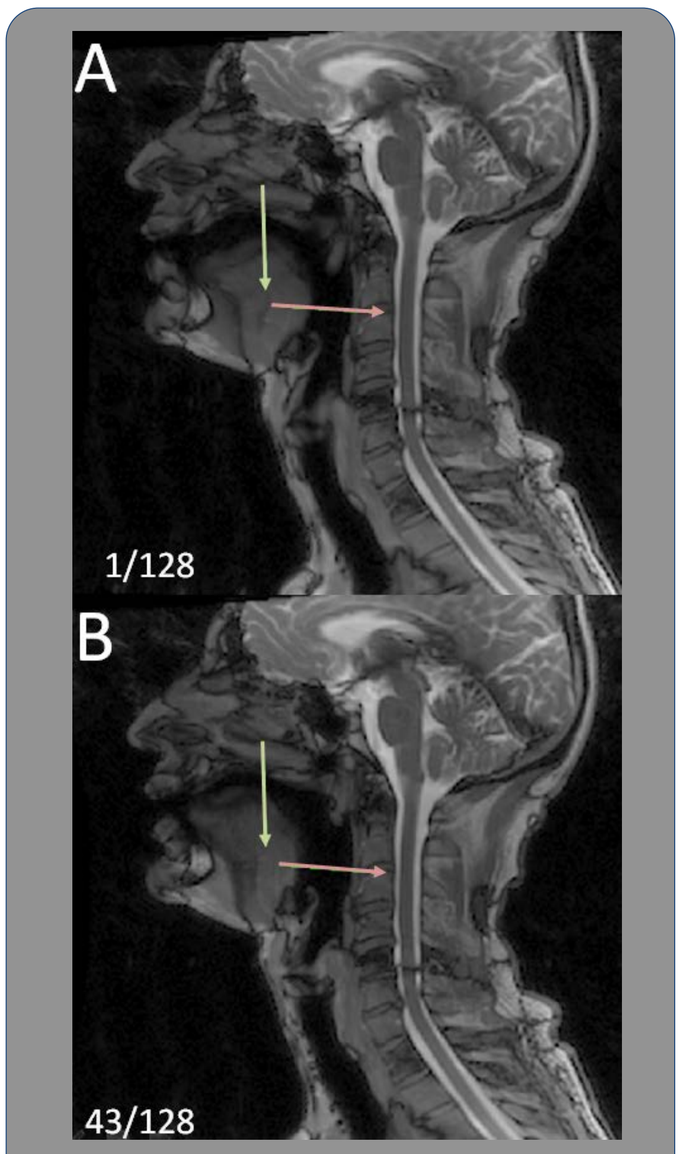


Fig 1. : Two temporal positions (A) 1 and (B) 43 of the 128 image **cine loop** of sagittal slice along the vocal tract with TM positions.

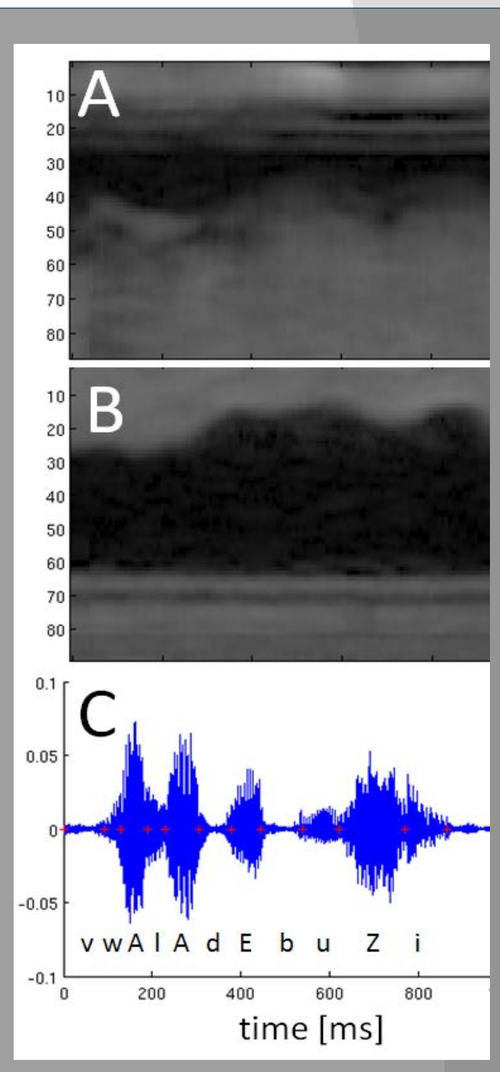


Fig 2. : Time motion display of the cine loop for (A) hard palate to tongue dorsum and (B) tongue back to pharyngeal wall, and (C) sound recording used for the **motion compensated reconstruction**.

Discussion and conclusion

- A potential issue with balanced-SSFP is related to the banding artifacts and the strong B_0 gradient at the air tissue interface especially in the tongue, but the signal void in the vocal tract is still **clearly distinguished** in the **dynamic movie**.
- Each cine loop enables the delineation of the **vocal tract** with **sufficient spatial and temporal resolution** enabling the acquisition of a **personalized speech model** within an MR examination of half an hour.

References : [1] Narayanan et al., J Acoust Soc Am, 115(4):1771 (2004) ; [2] Frauenrath et al., Act Acus, 94(1):148 (2008); [3] Odille et al. MRM. 60:146-157 (2008); [4] Batchelor et al. MRM. 54:1273-1280 (2005) ; [5] Maeda, Actes X JEP, p152, Grenoble (1979) ; [6] Ozerov et al., IEEE TASLP, 20(4) :1118 (2012); [7] Vuissoz et al., JMRI, 35 :340 (2012);

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