

30 juin 2022 Formation doctorale Mulhouse

## Formation doctorale GdR TACT

*Principes physiques de fonctionnement des stimulateurs tactiles*

Anis KACI, Université de Lille, L2EP-IRCICA



TACT: le **T**oucher, **A**nalyse, **C**onnaissance, simula**T**ion

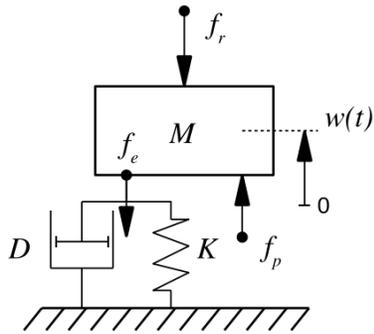
Le toucher: approche pluridisciplinaire

- Sciences du contact
- Neurosciences
- Psychologie cognitive
- Mécatronique

→ Connaissance a minima des domaines connexes

→ Formation pour doctorants, post-docs, dans ce sens

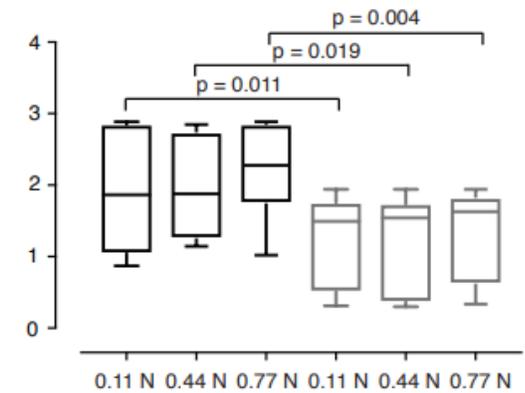
## Mécanique



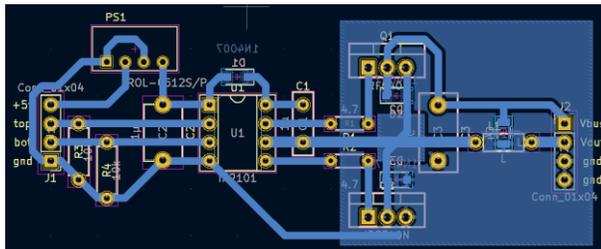
## Informatique

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11 <script type="text/javascript">
12 <script type="text/javascript">
13 (function(){
14   onLoaded: function(request) {
15     if (request.name == 'log_error') return;
16     log_trace("Ajax.Request: " + (request.name || request.url.substr(0, 30)) + "...");
17   };
18   onComplete: function(request) {
19     if (request.name == 'log_error') return;
20     log_fatal(request.url + " " + e.name + " | " + e.message + " | " + e.stack);
21   };
22 }
```

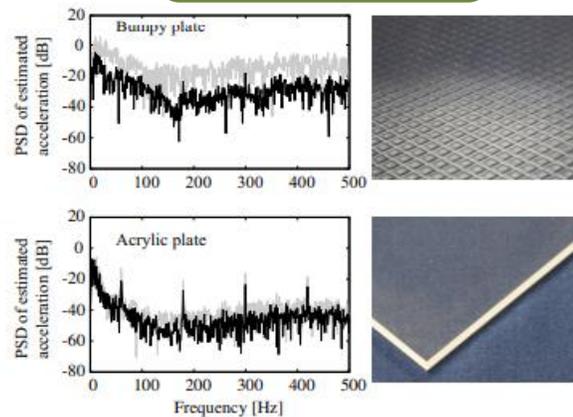
## Statistiques



## Electronique

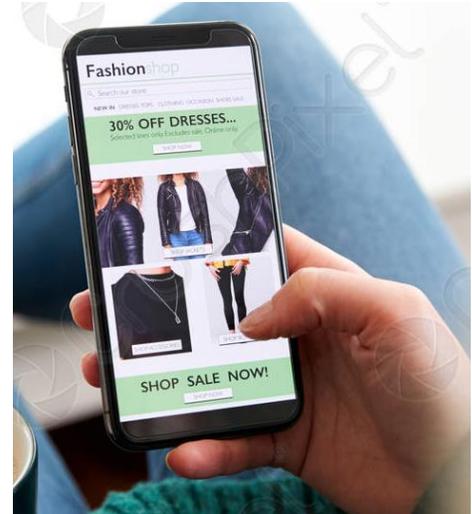
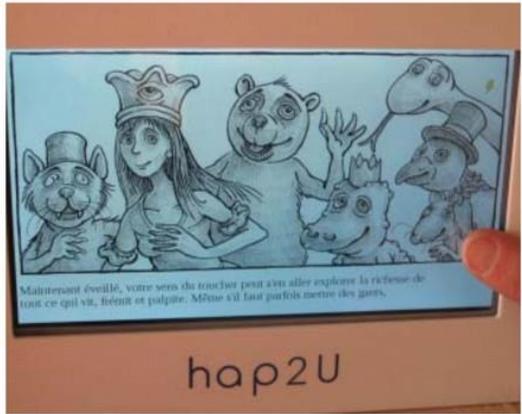


## Traitement de signal





[Cagatay\_A\_review\_2020]



# 1. Classification des stimulateurs tactiles

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## Dispositifs haptiques

- Simuler le retour haptique que procurent les objets
- Classification en retour d'effort et retour tactile

### 1 Retour d'effort (kinesthésique)

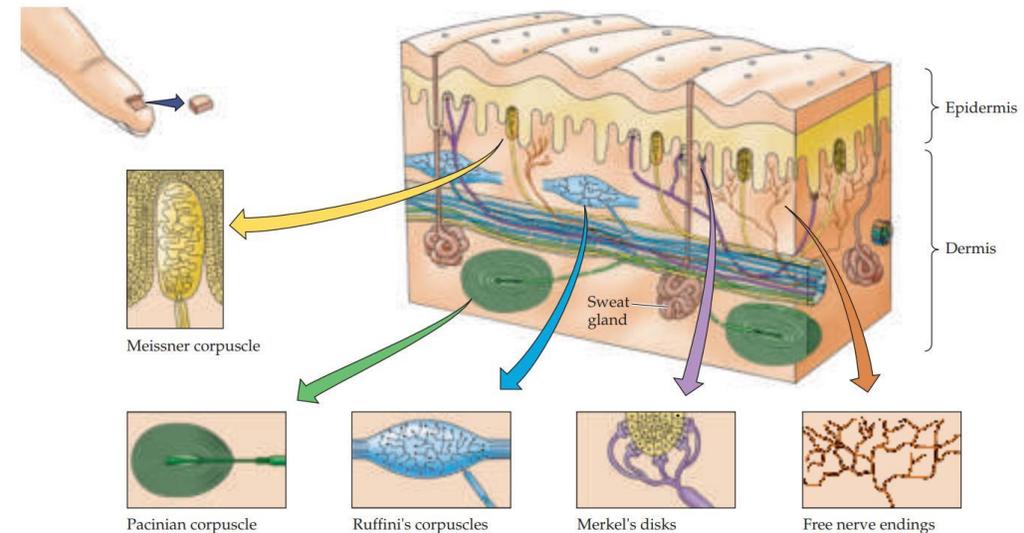
- Lié à la perception de force, de poids, d'élasticité et d'inertie
- Fait intervenir les muscles, les tendons et les articulations

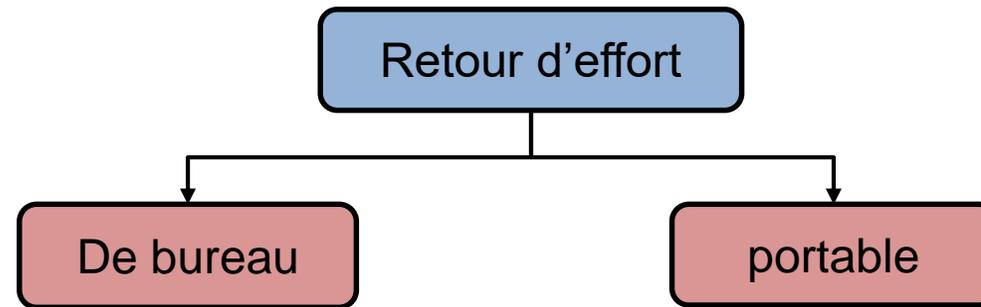
## Mécanorécepteurs

- Corpuscules de Meissner : captent les vibrations de basses fréquences 10-100Hz
- Corpuscules de Pacini : captent les vibrations de hautes fréquences 40-1000Hz
- Corpuscules de Ruffini : sensibles aux cisaillements de la peau
- Disques de Merkel : sensibles aux déformations statiques

### 2 Retour tactile (cutané)

- Lié à des sensations subtiles comme la texture, la rugosité et les vibrations
- Implique les mécanorécepteurs

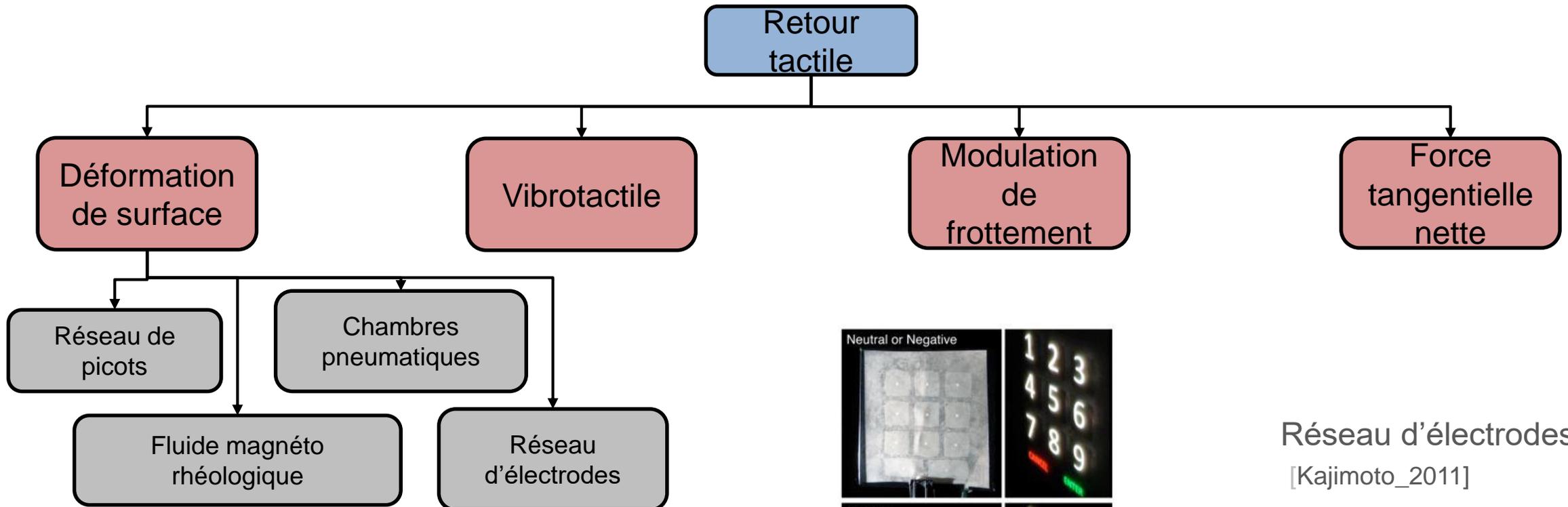




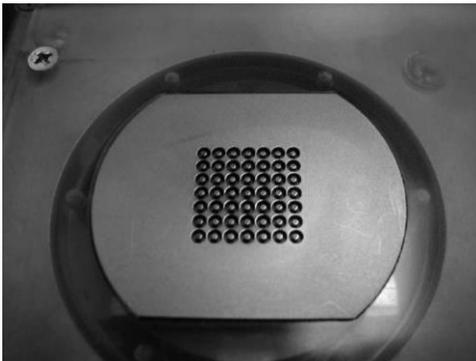
« Force Dimension Inc »



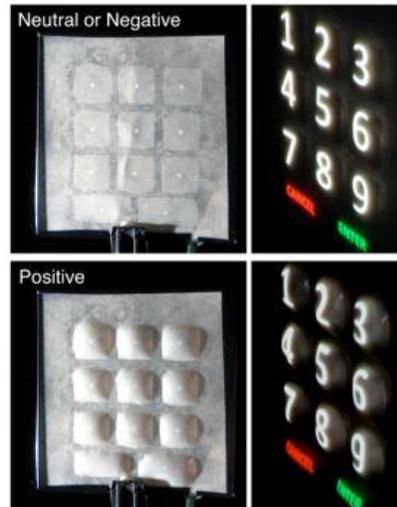
« GotouchVR »



Réseau de picots [Shinogara\_1998]

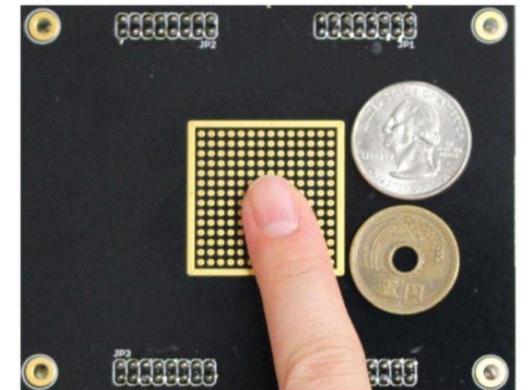


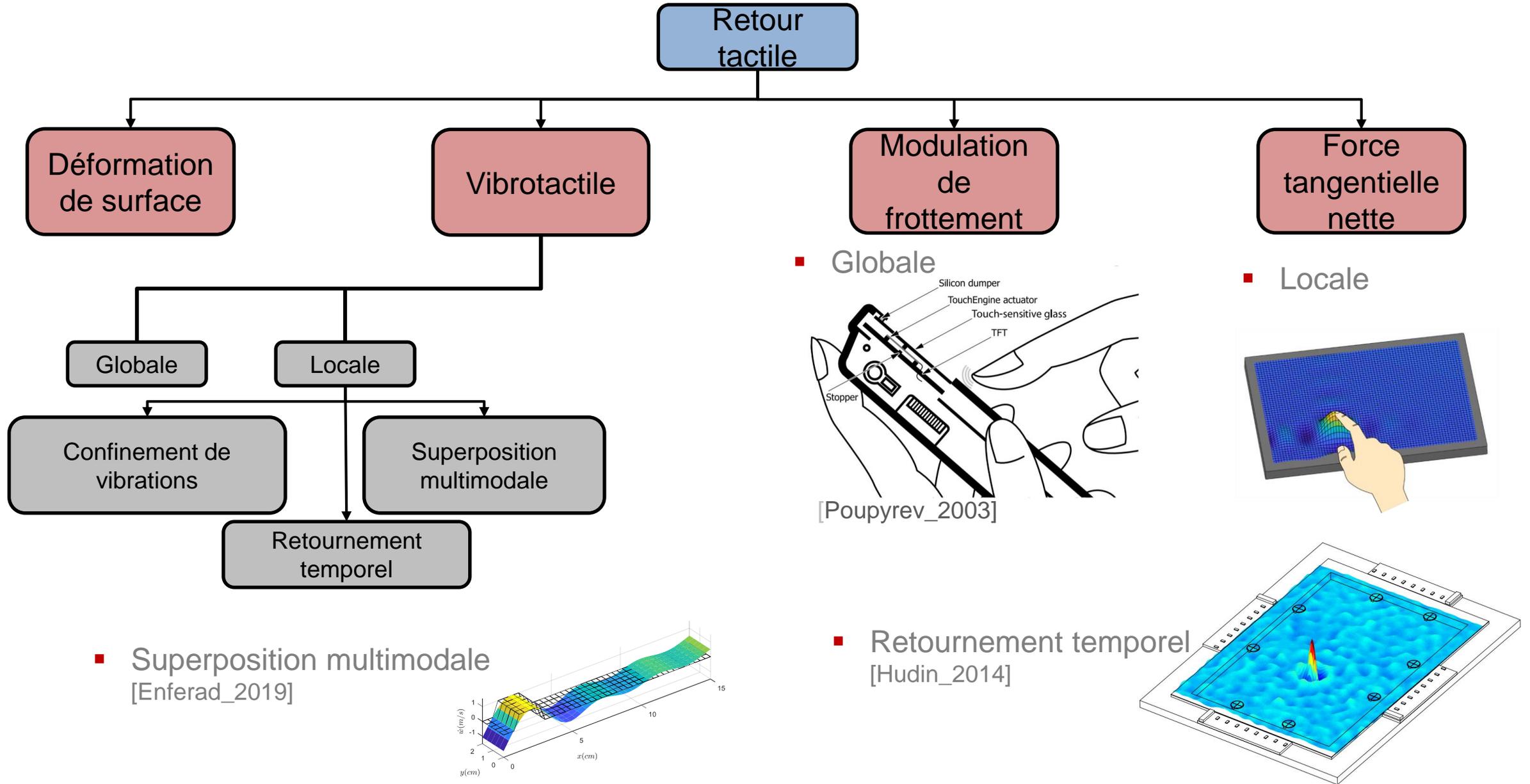
Fluide magnéto rhéologique [Jansen\_Mudpad\_2010]



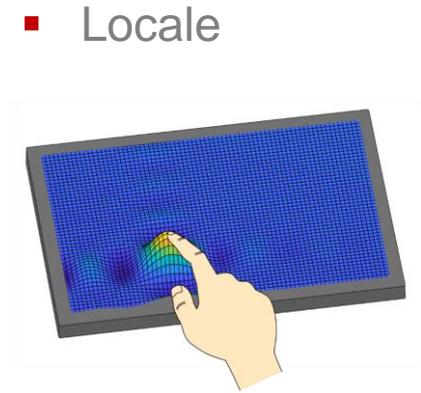
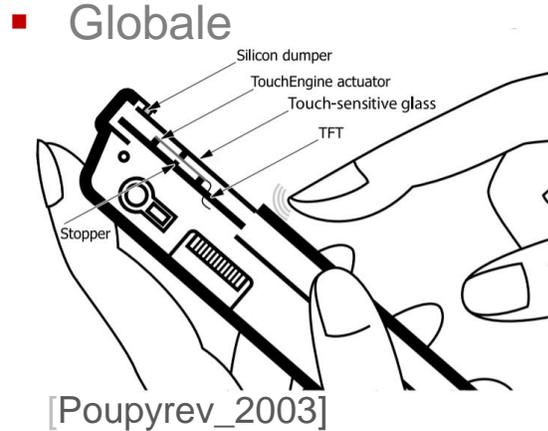
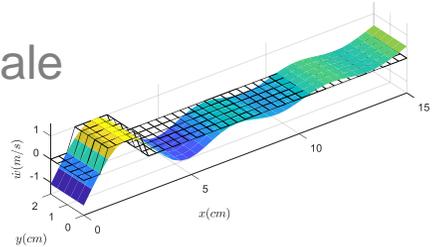
Chambres pneumatiques [Harrison\_2009]

Réseau d'électrodes [Kajimoto\_2011]

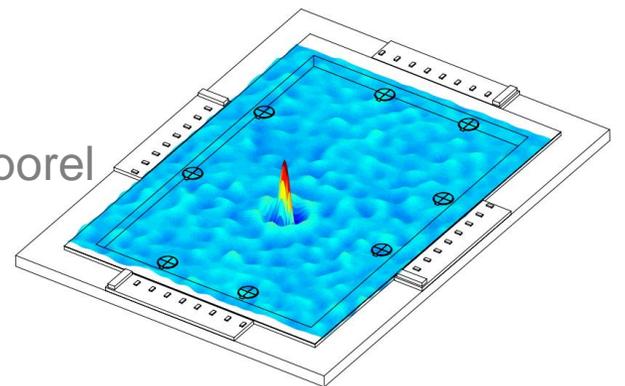


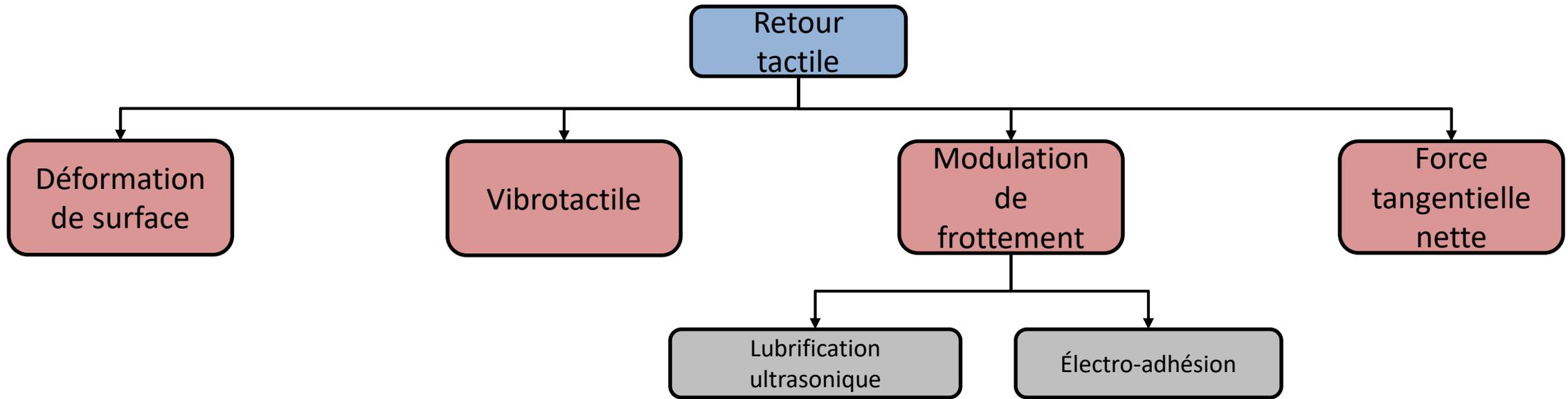


- Superposition multimodale [Enferad\_2019]

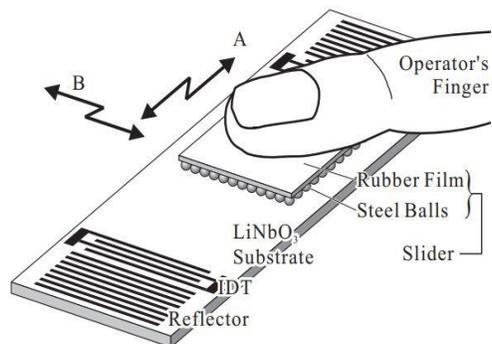


- Retournement temporel [Hudin\_2014]

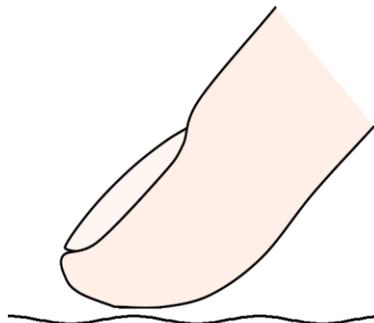




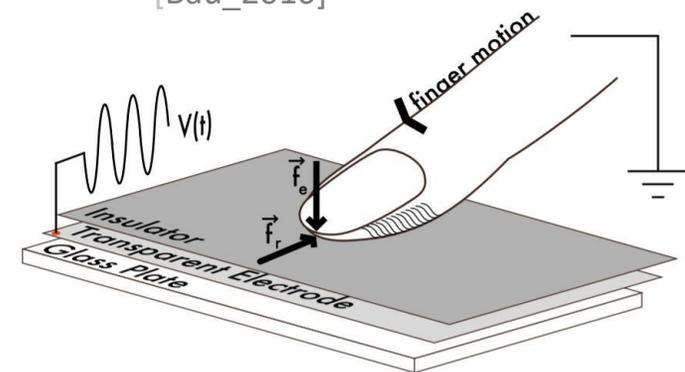
- Lubrification ultrasonique par Ondes acoustiques de surface [Takasaki\_2006]

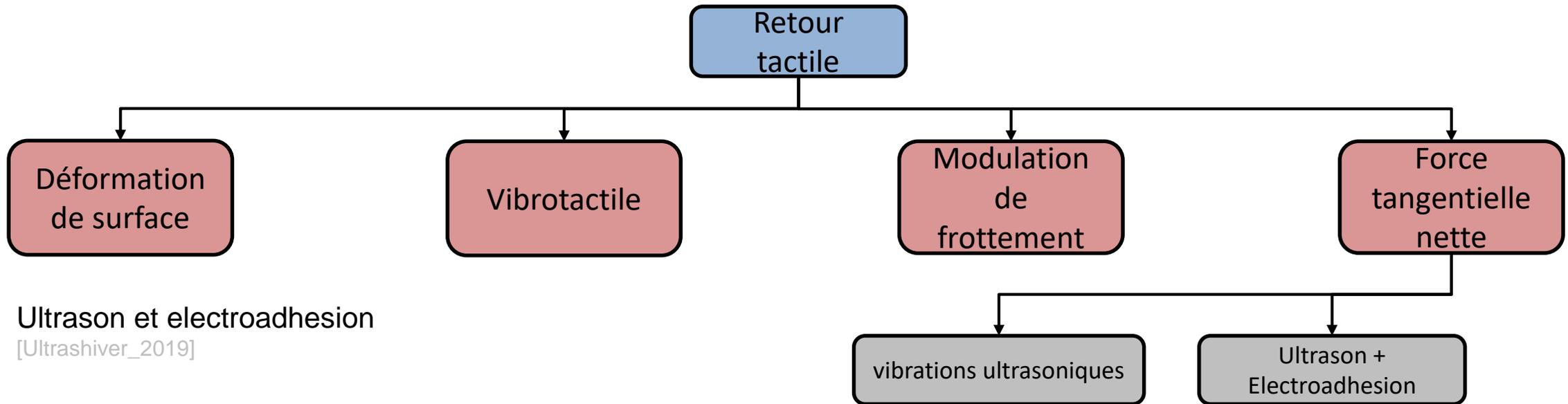


- Lubrification ultrasonique basse fréquence [Watanabe\_1995]

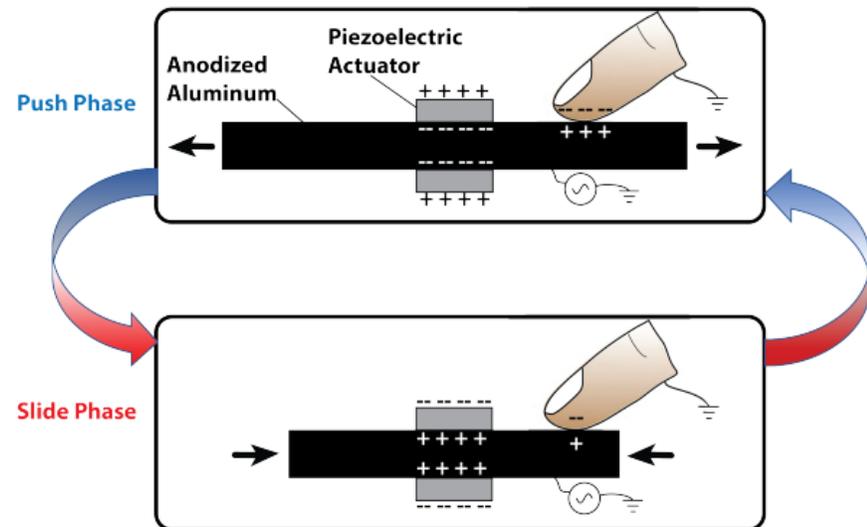


- Électro-adhésion [Bau\_2010]

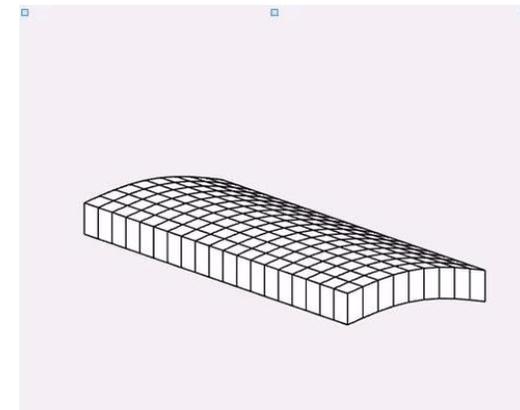




Ultrasound and electroadhesion  
[Ultrasher\_2019]



Two modes of ultrasonic vibration  
[Garcia\_control\_2022]



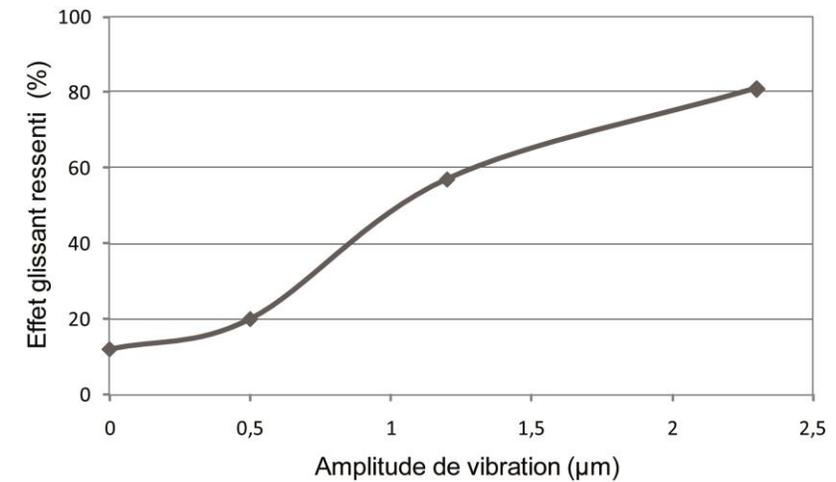
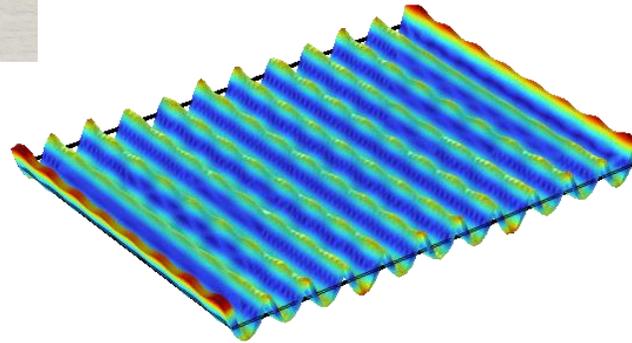
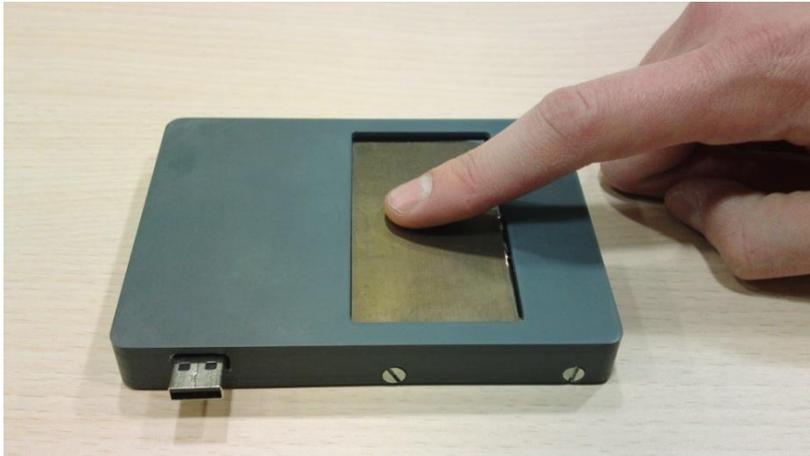
## 2. Stimulateurs tactiles contrôlant le frottement

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## - Grâce à la lubrification ultrasonique

Vibrations  $>20\text{kHz}$  (onde stationnaire)

- Non perceptible par la main humaine
- Contact intermittent, diminution du frottement
- Effet « glissant »

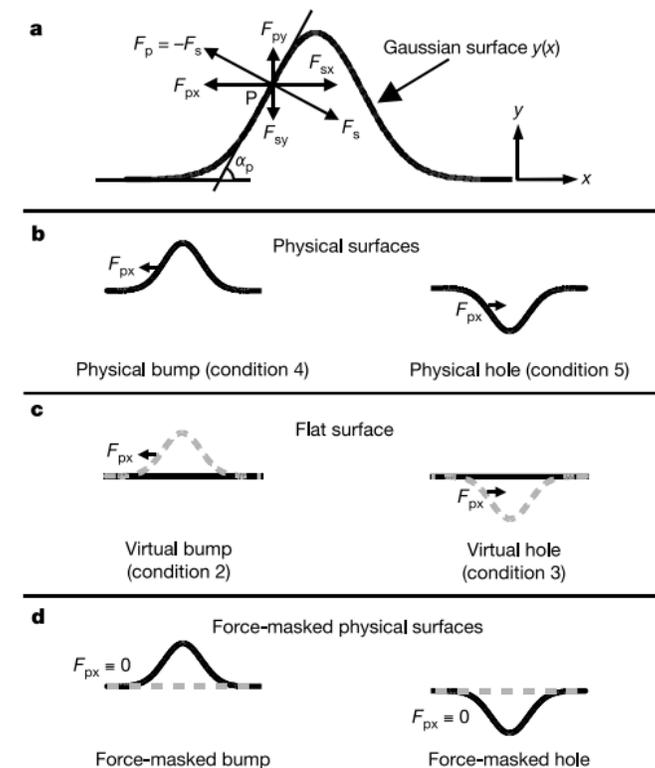
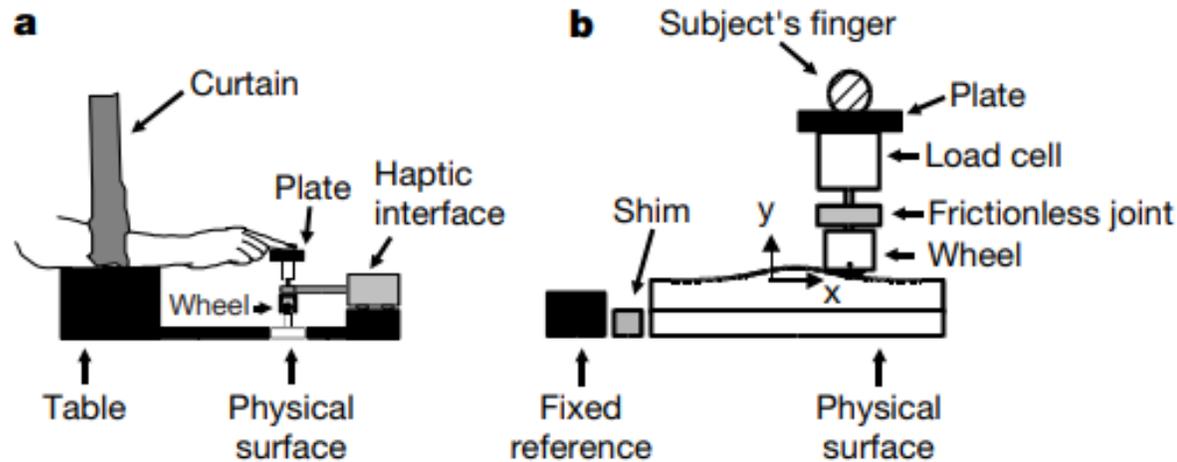


## Force can overcome object geometry in the perception of shape through active touch

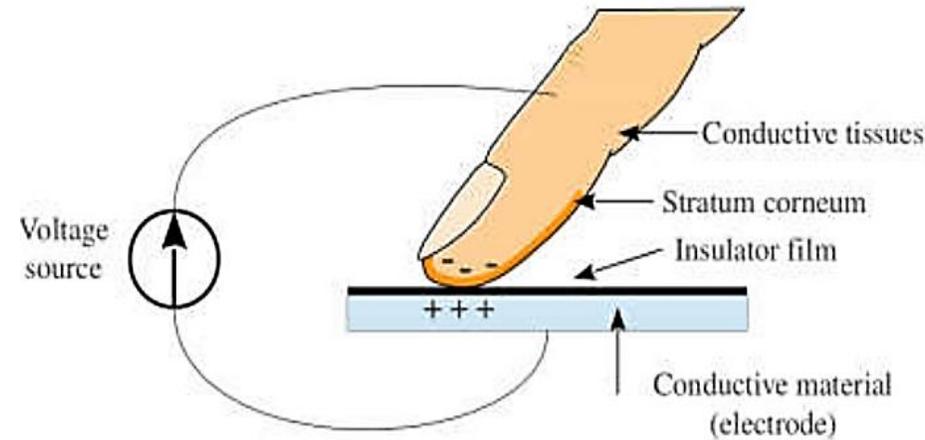
Gabriel Robles-De-La-Torre & Vincent Hayward

McGill University, Center for Intelligent Machines, Montréal, Canada H3A 2A7

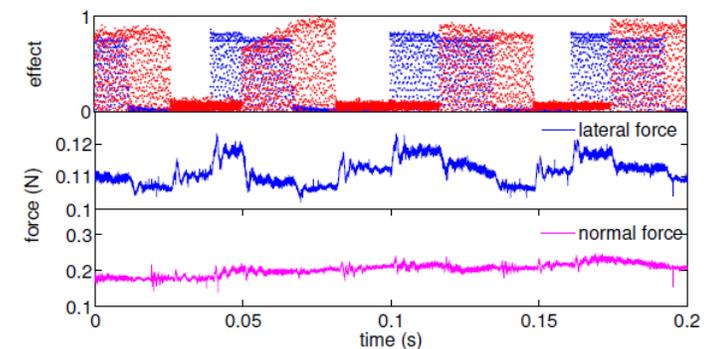
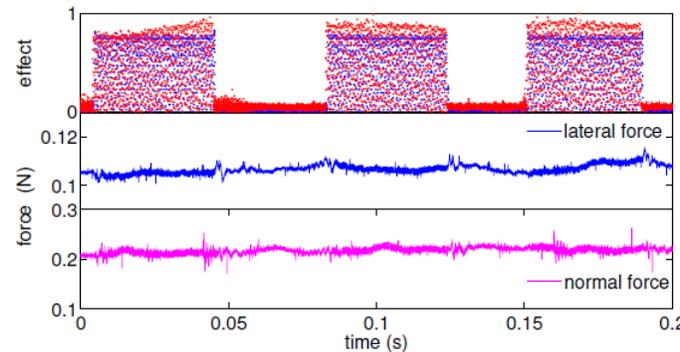
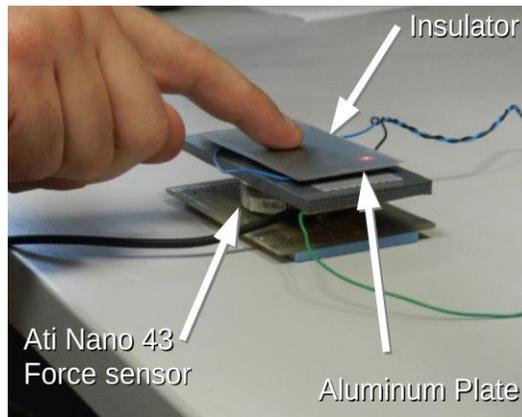
- Simuler une variation de hauteur d'une surface comme une bosse ou un trou
- Reproduire la force latérale due à l'exploration d'un doigt sur ces deux surface



- Grâce à l'électro-adhésion: principe d'augmentation du frottement



## Possibilités de couplage ondes acoustiques et électro-adhésion



## - Avantages de ces stimulateurs

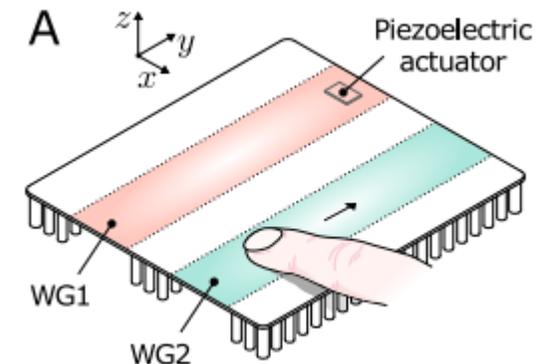
- Possibilités d'atteindre une forte compacité
- Possibilités de mettre en vibration des surfaces transparentes (écrans)
- Contrôle bien maîtrisé, robustesse par rapport au doigt

## - Inconvénients:

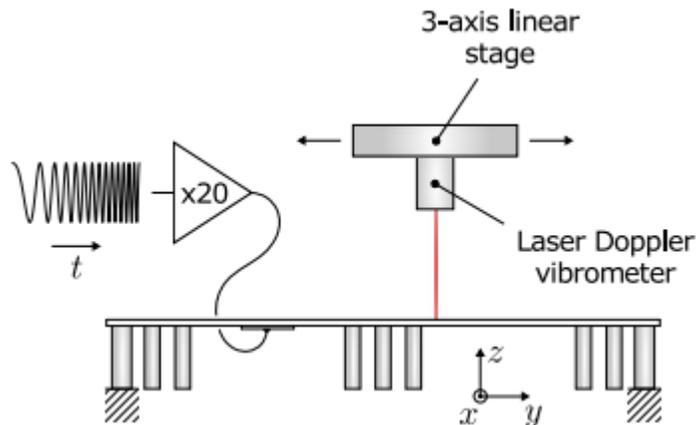
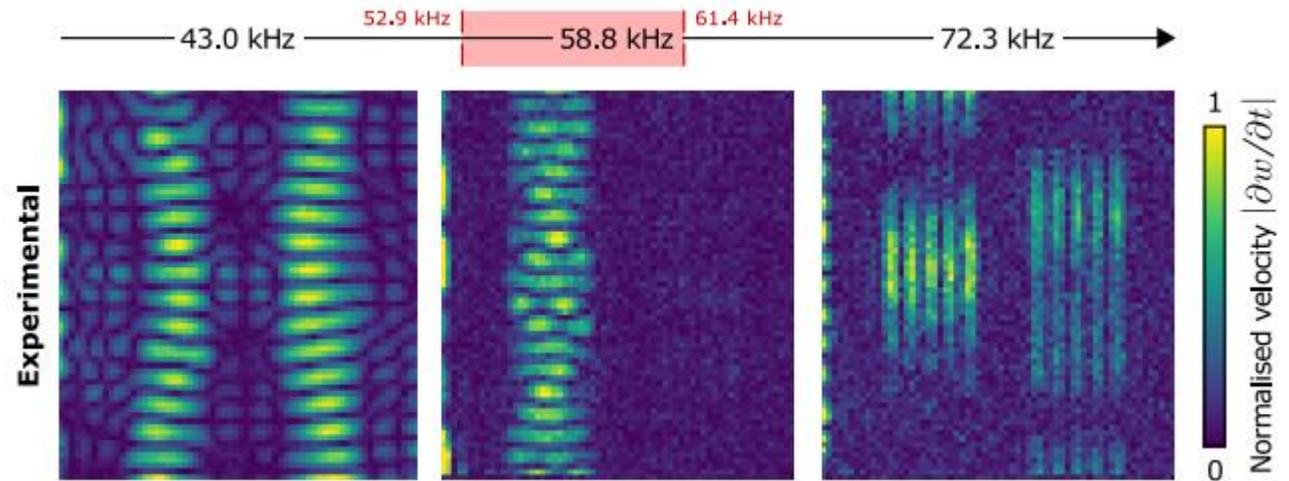
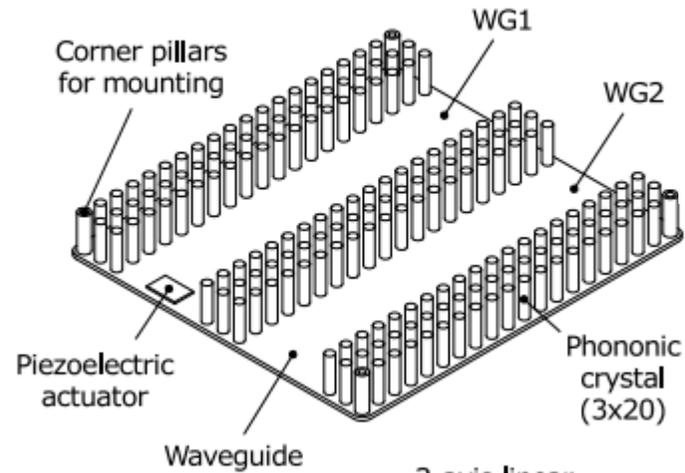
- Pas d'effet tactile doigt statique
- Pas de possibilités de retour multi-doigts



Solution: réaliser des guides d'onde

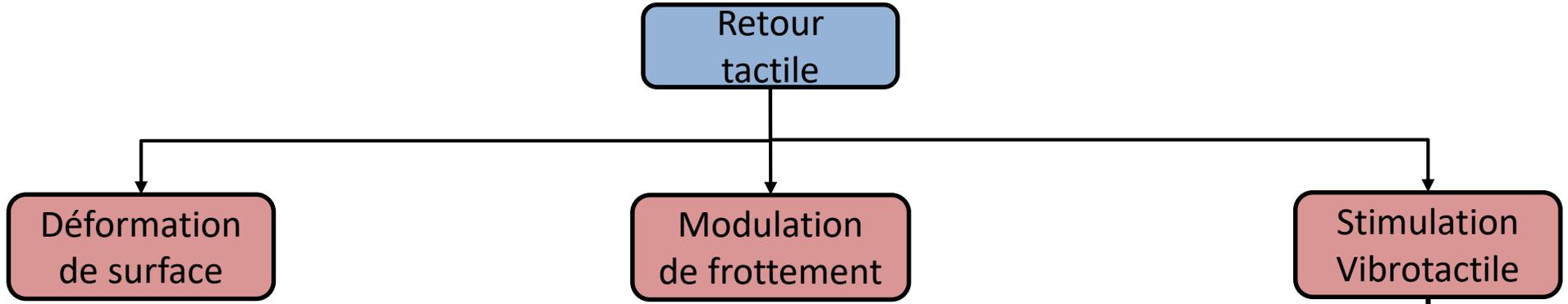


- Exemple de surface équipée de guides d'onde

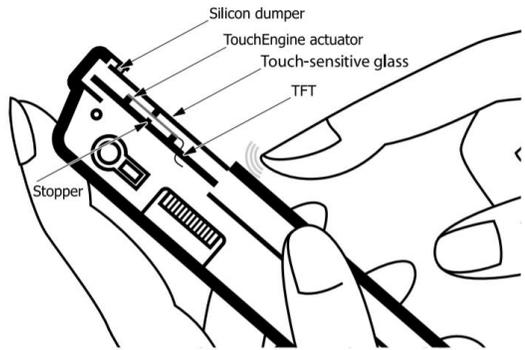


### **3. Stimulateurs vibrotactiles localisés**

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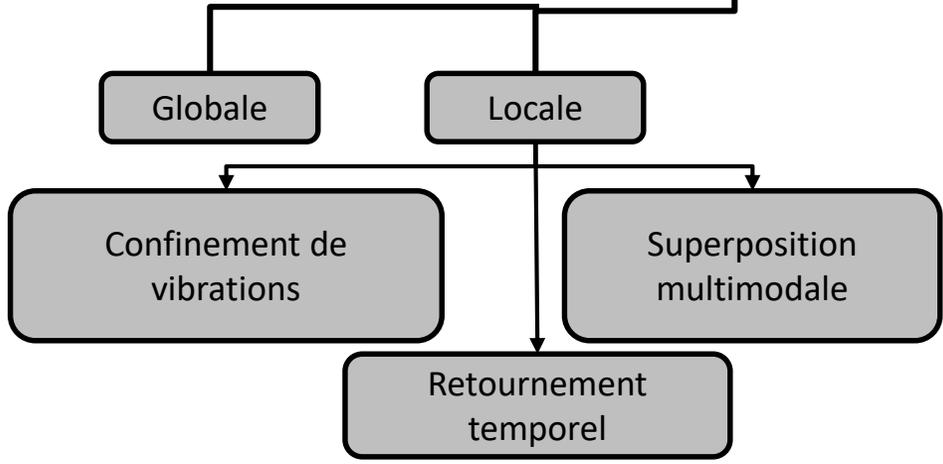
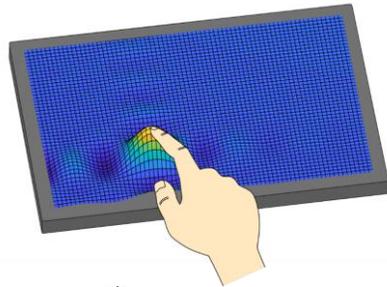


■ Globale

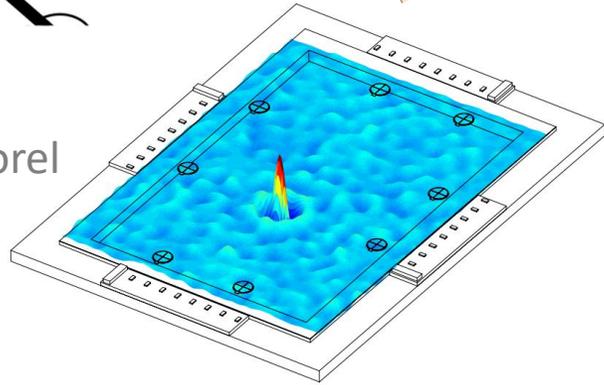


[Poupyrev\_Tactile\_2003]

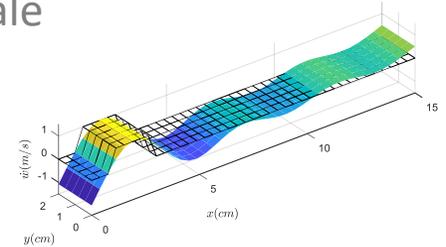
■ Locale



■ Retournement temporel [Hudin\_2014]

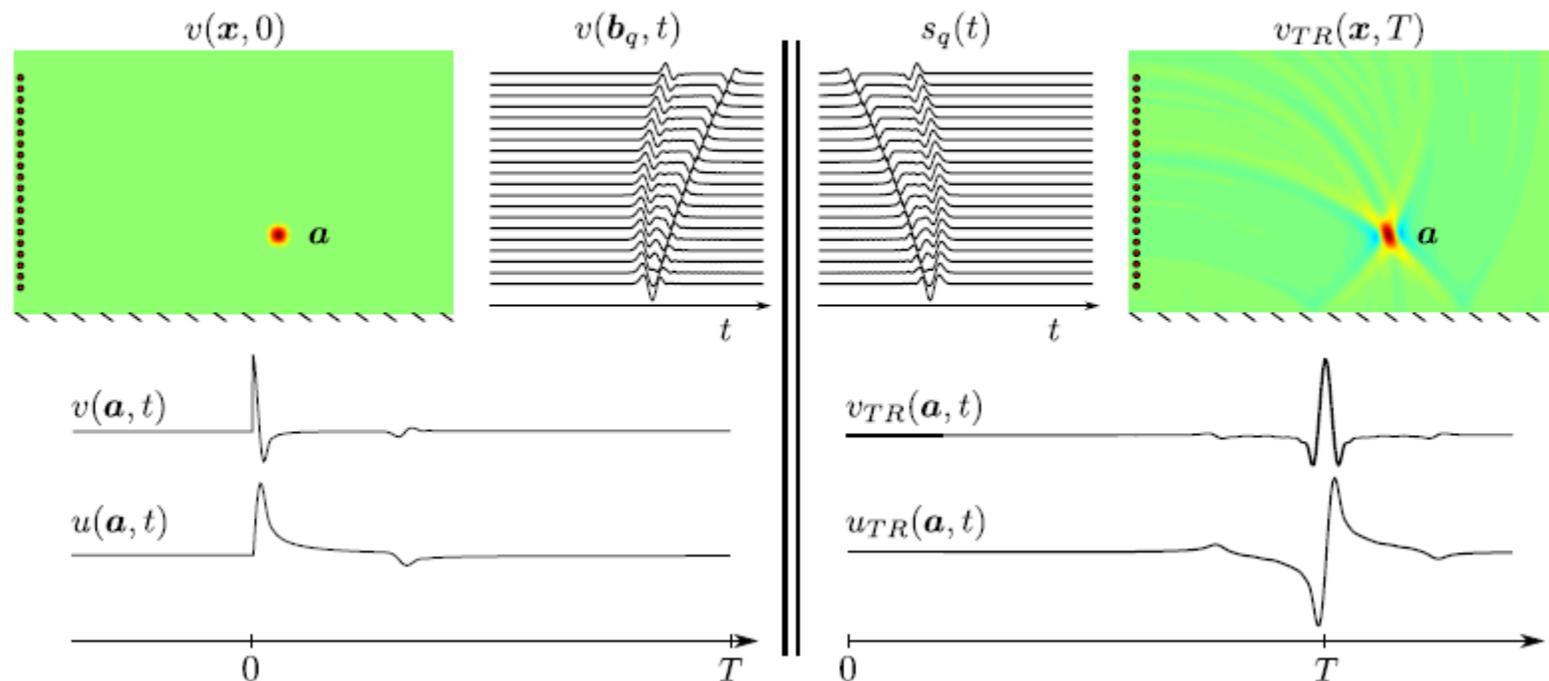


■ Superposition multimodale [Enferad\_2019]

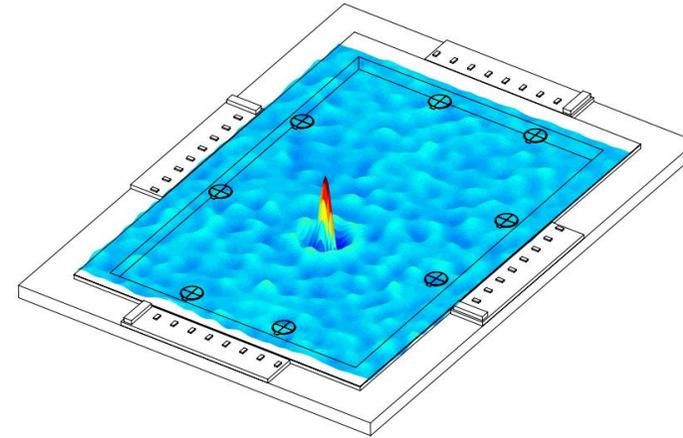
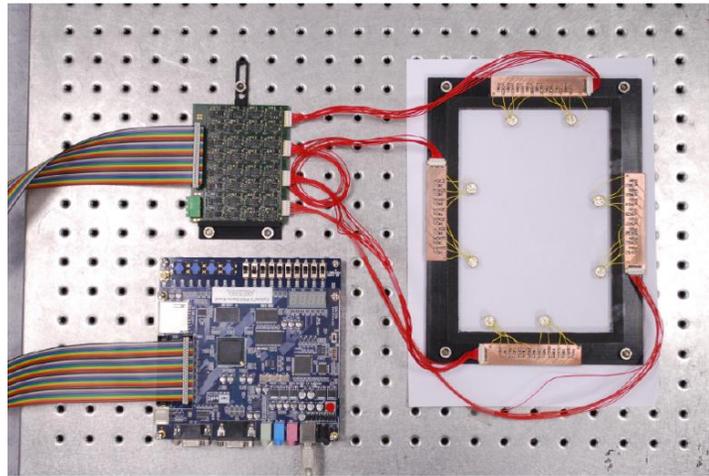


## -Par retournement temporel: principe

- Impulsion initiale créée en  $a$
- Onde générée se propage et est enregistrée par les transducteurs
- Ces transducteurs rejouent les signaux inversés temporellement
- L'impulsion initiale est recrée en  $a$



## -Par retournement temporel: principe



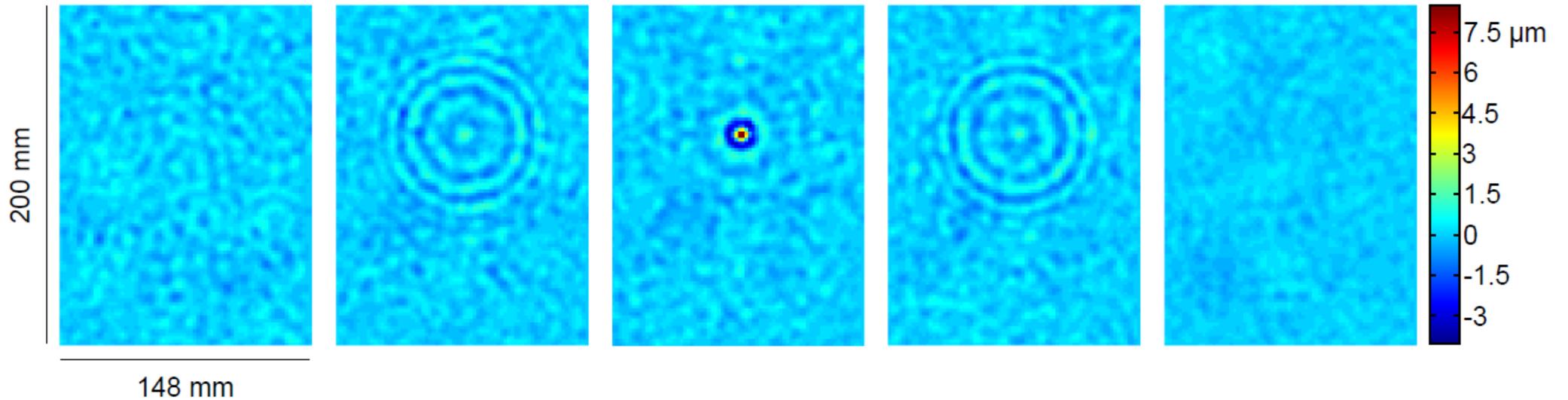
t=1 ms

t=1.96 ms

t=2 ms

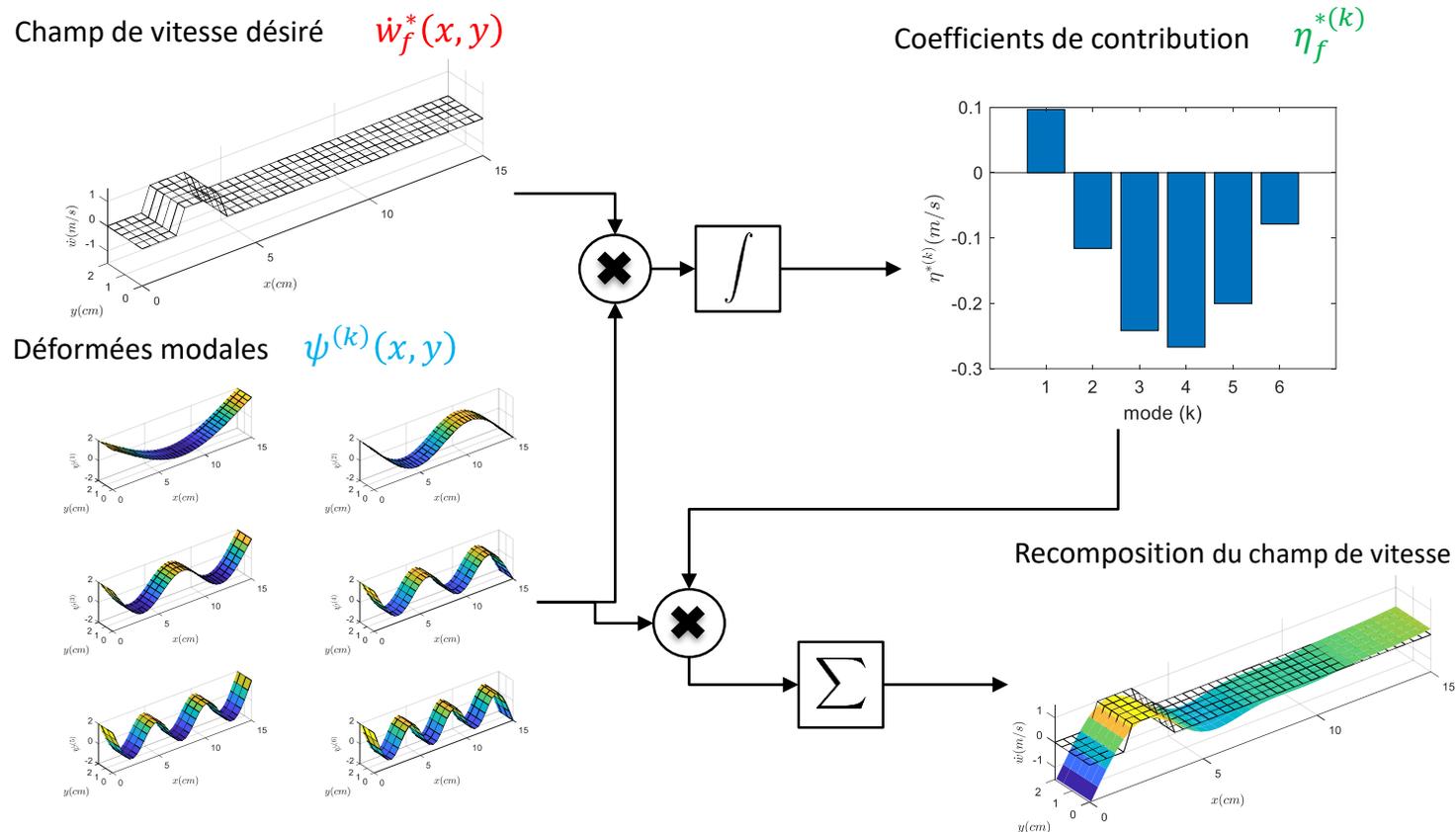
t=2.04 ms

t=3 ms



## -Par superposition multi-modale

- Créer un effet localisé sans pré-enregistrer les ondes
- Combiner ou superposer des modes de plaque

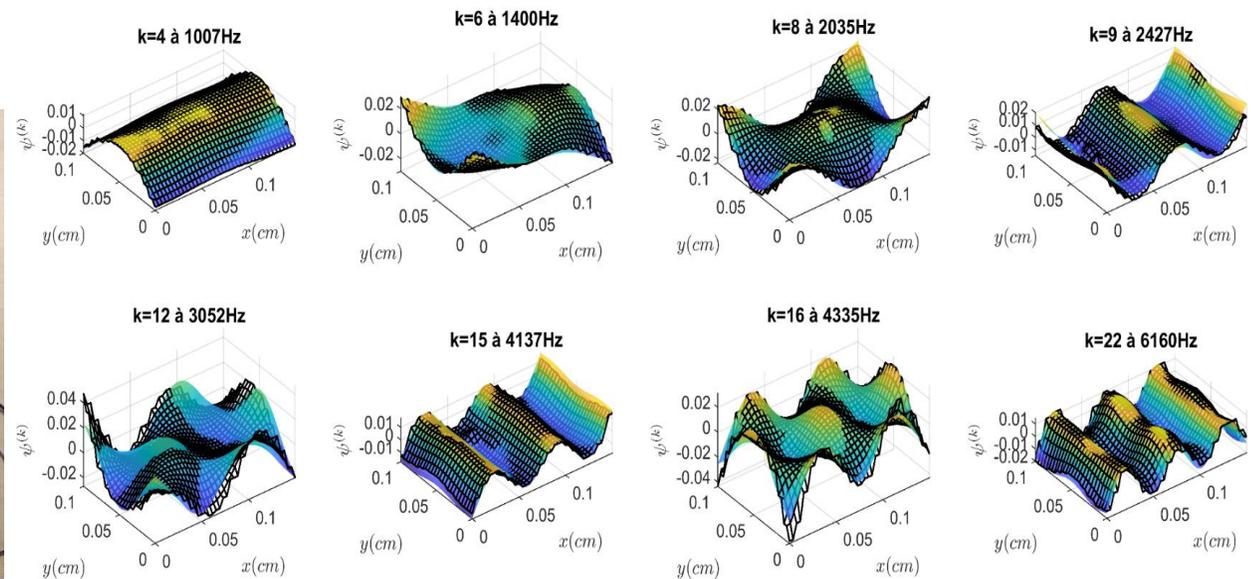
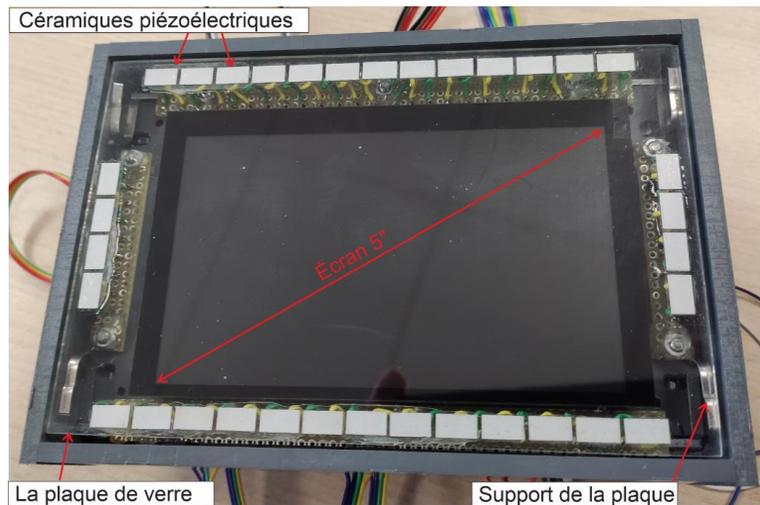


## -Par superposition multi-modale

- Créer un effet localisé sans pré-enregistrer les ondes
- Combiner ou superposer des modes de plaque

### ■ Identification des modes

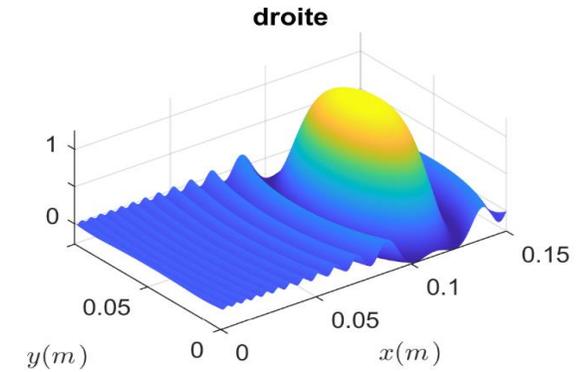
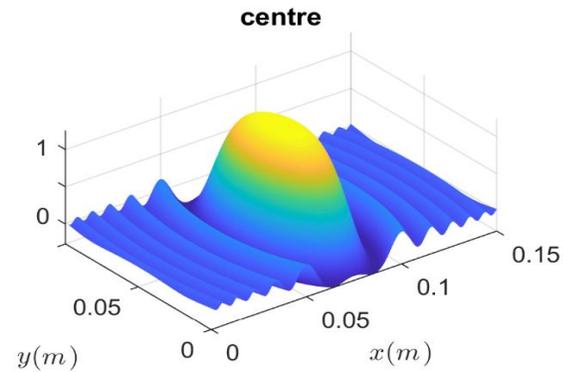
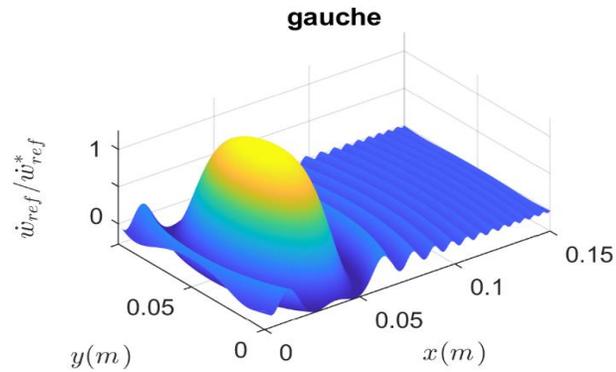
### ■ Mise en œuvre de la plaque



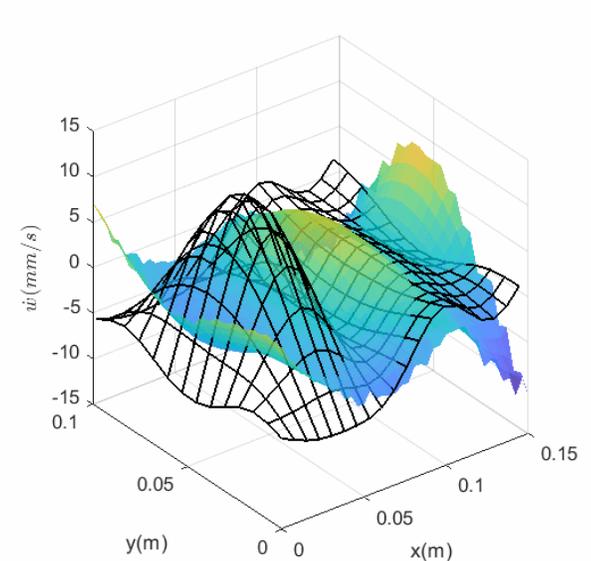
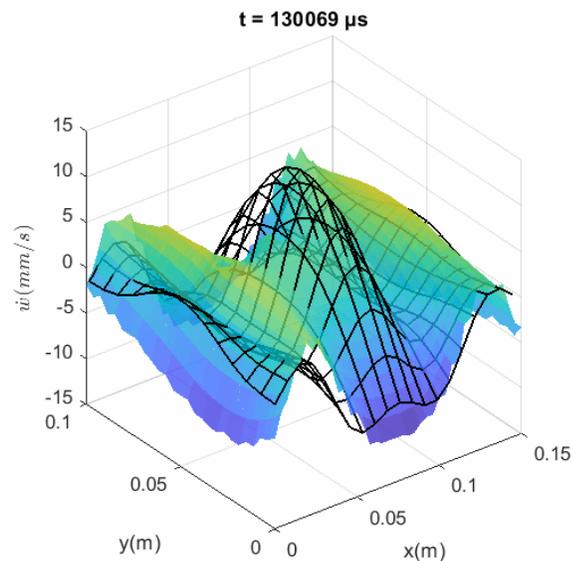
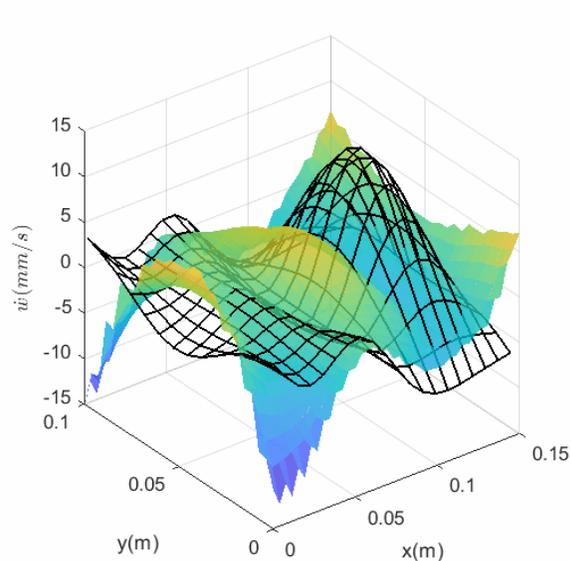
## -Par superposition multi-modale

Kaci A. PhD thesis, Université de Lille, 2020

- Champs de vitesse définis comme références

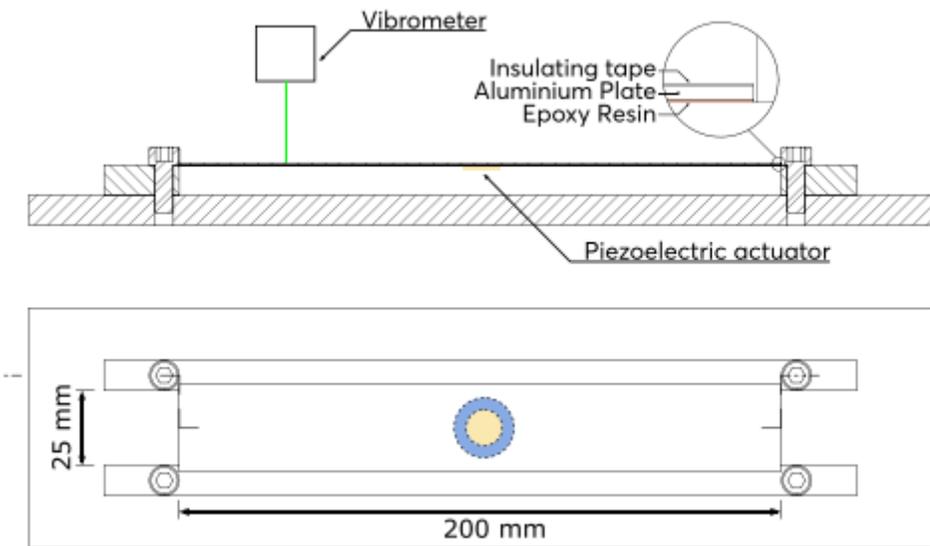
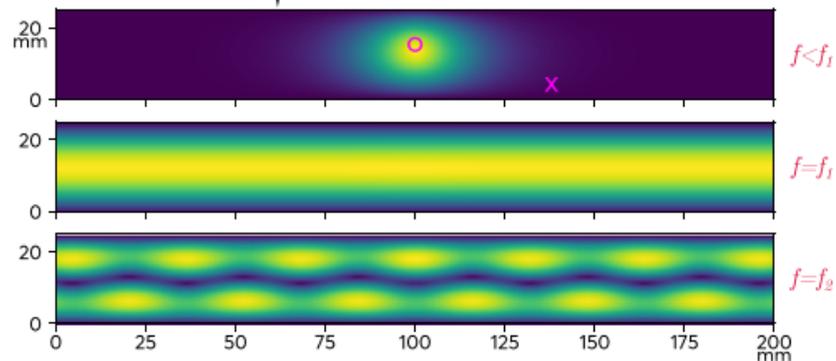
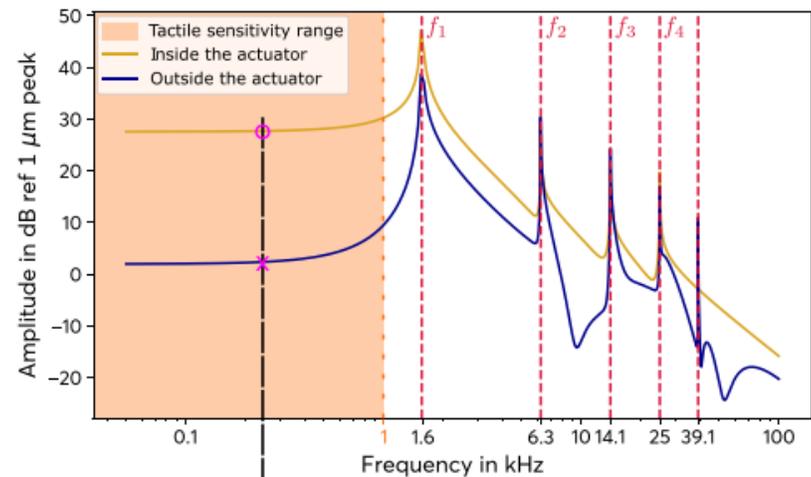


- Champs de vitesse recomposés

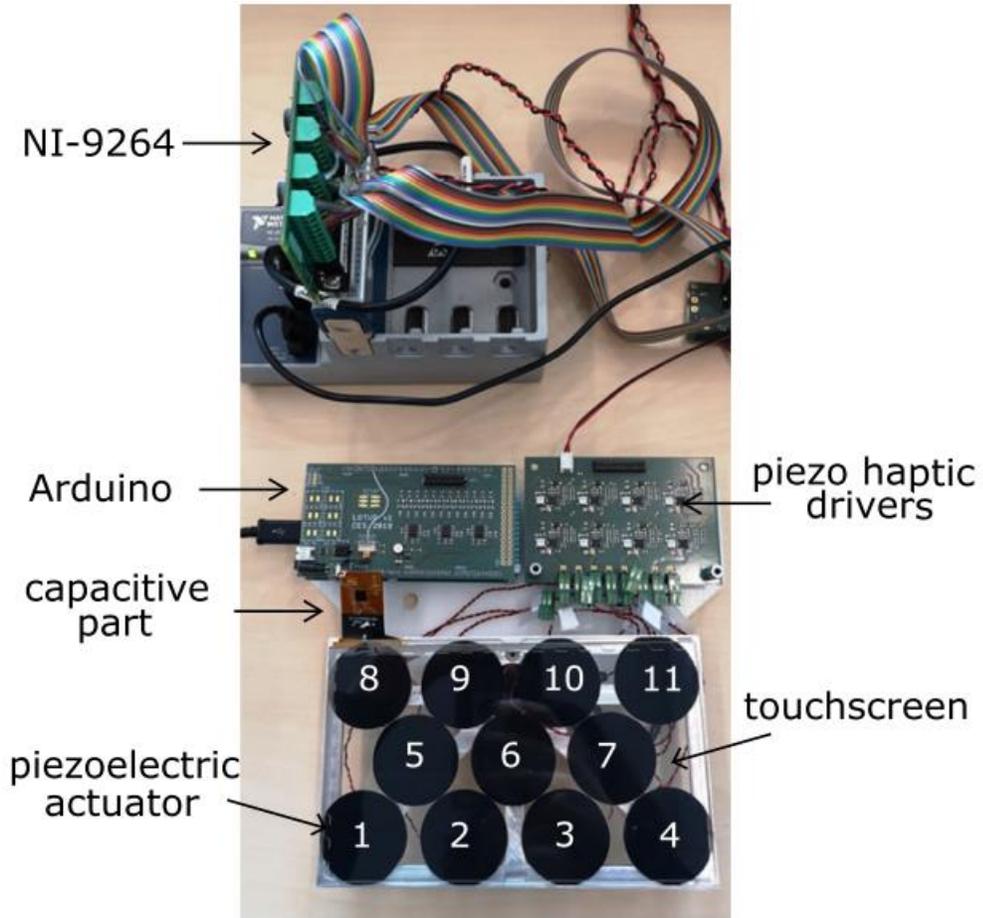


## -Par confinement de vibrations

- Travail à des fréquences qui ne génèrent pas des modes de vibrations (ondes évanescentes)
- Vibration localisée sur l'actionneur



## -Par filtrage inverse



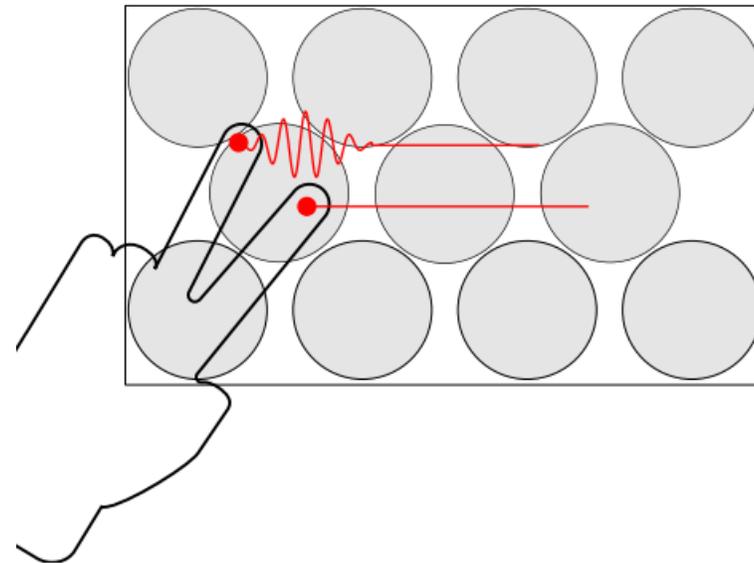
$$\begin{pmatrix} U_1 \\ U_2 \\ \vdots \\ U_F \end{pmatrix} = \begin{pmatrix} H_{11} & H_{12} & \dots & H_{1Q} \\ H_{21} & H_{22} & \dots & H_{2Q} \\ \vdots & \vdots & \ddots & \vdots \\ H_{F1} & H_{F2} & \dots & H_{FQ} \end{pmatrix} \begin{pmatrix} S_1 \\ S_2 \\ \vdots \\ S_Q \end{pmatrix}$$

$$S[Q, N_s] = H^{-1}[Q, F, N_s] \cdot U[F, N_s]$$

$$\downarrow \text{IFFT}$$

$$s(t) [Q, N_s]$$

### Multitouch Feedback

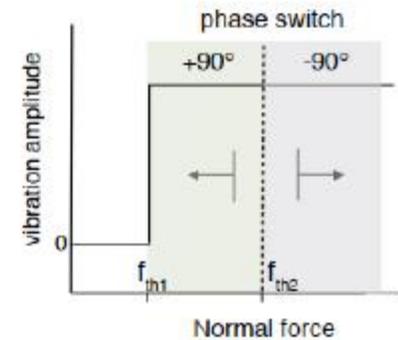
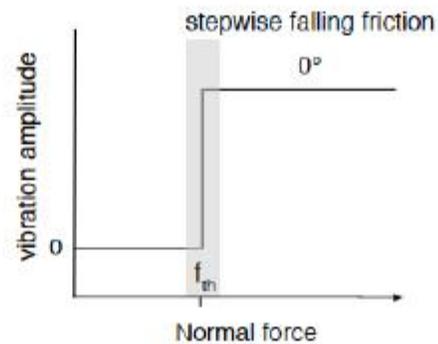
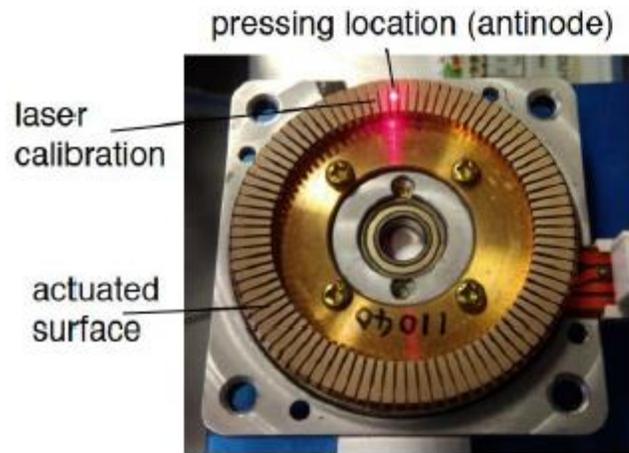


### 3. Stimulateurs par force tangentielle nette

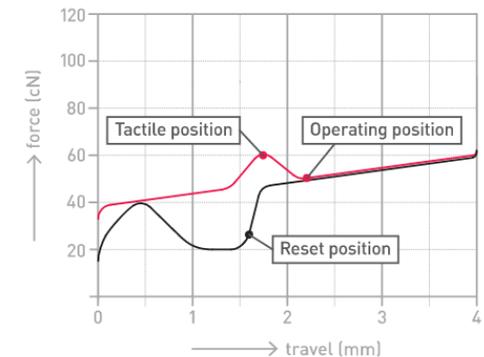
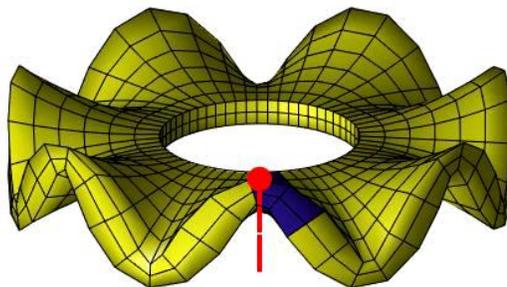
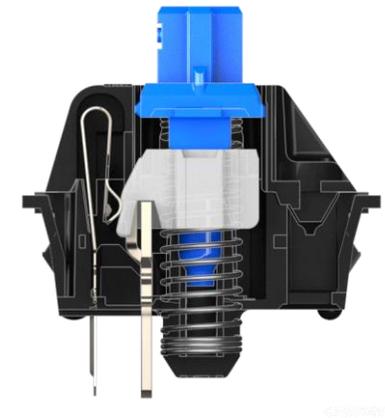
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## -Par superposition de deux modes ultrasoniques

- Utilisation d'ondes progressives ou de modes couplés
- Changement de phase (inversion de sens) lors de la pression du doigt

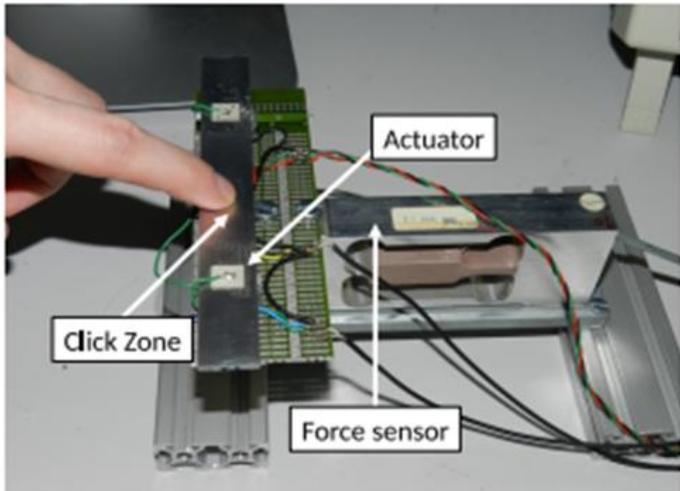


Touche de clavier

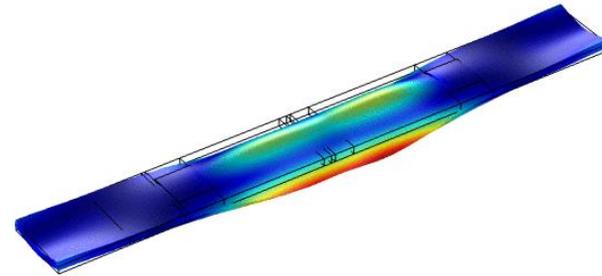


## -Par changement de direction d'onde

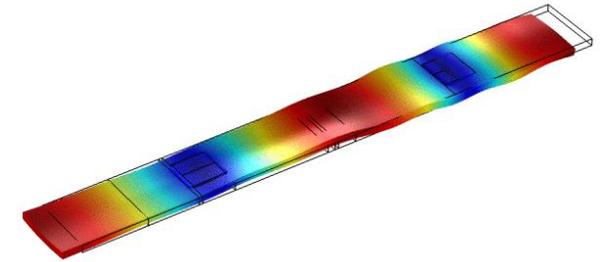
- Exemple de réalisation d'une stimulation localisée avec modes couplés



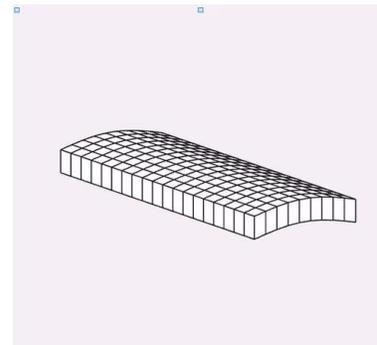
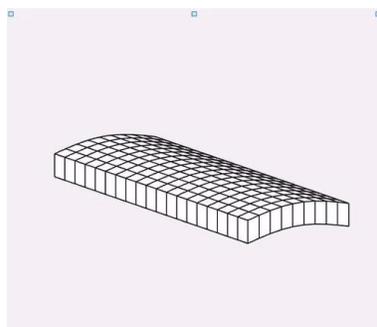
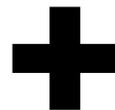
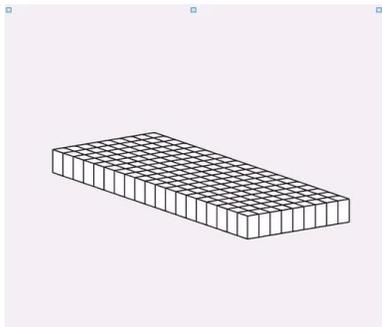
Stimulateur



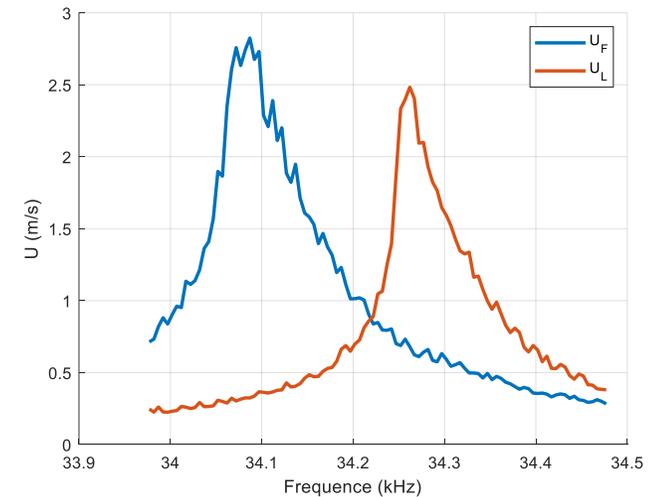
Mode de flexion 34 539 Hz



Mode Longitudinal 34 645 Hz



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## Merci pour votre attention

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- [2] D. Wang, Y. Guo, S. Liu, Y. Zhang, W. Xu, and J. Xiao, 'Haptic display for virtual reality: progress and challenges', *Virtual Reality & Intelligent Hardware*, vol. 1, no. 2, pp. 136–162, Apr. 2019.

