Research Portfolio

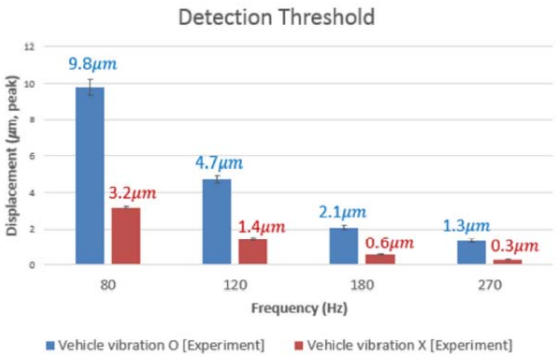
Applicants : Kim Sung Hyun

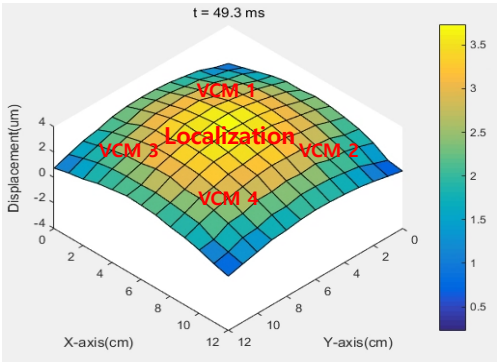
Gwangju Institute of Science and Technology

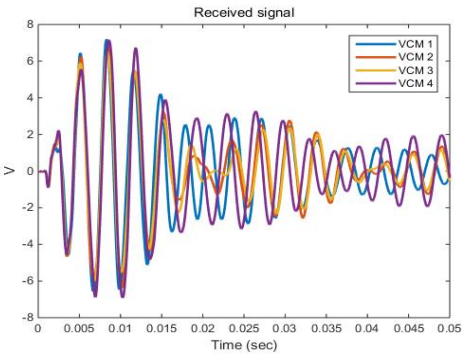
Contents

Knowledge and Experience

- **Knowledge, Interest** : Mechanical Design, Vibrotactile Perception, Bending Wave Haptics, Signal Processing







Figures of Contribution

- **Mechanical Design project** in undergraduate **CAD** course (Based on **Pro-e**)
- **Industrial project** with **UI/UX** Research team in **LG Display**
  - 2016. 02. 01 ~ 2016. 07. 31, 'Development and Evaluation of Haptic Display for Automotive'
  - 2017. 03. 01 ~ Present : 'Development of Automotive Haptic Display Module using VCM / POLED'
- **Paper**
  - Preliminary Evaluation of Click Feedback Sensitivity According to Direction of Vibration of Automotive Haptic Displays, **Korea Haptics Community**, 2016
  - Preliminary User Evaluation of Haptic Display Click Feedback in Automotive Environment, **The Korean Society of Automotive Engineers**, 2016
  - Preliminary Quantitative Evaluation of Haptic Display Click Feedback in Automotive Environment, **The Korean Society of Mechanical Engineers**, 2017
  - Design and Evaluation for Click Feedback of Vibrotactile Display in Automotive Environment, M.S. Thesis, 2017

Mechanical Design Project Summary

Mechanical Design Project Summary

- **Title** : Design and Mechanical Implementation of an Electric Fan
- **Motivation**

  - Design and Mechanical Implementation of Mechanical Product as same as possible

- **Contribution**

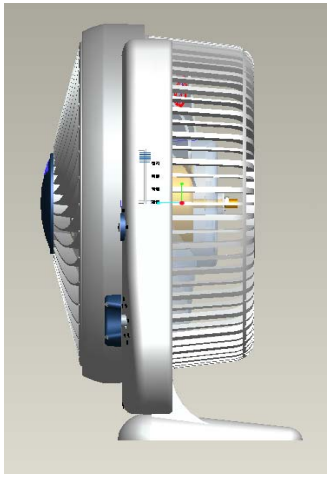
  1. 3 Dimensional Design for each Part of Electric Fan
  2. Assembly all the Parts to Construct Electric Fan
  3. Mechanical Implementation like Real Mechanism

3D Design

Floor Plan

Real Electric Fan

Designed Electric Fan



Right side view

Animation for Disassembly

Animation for Mechanical Implementation

Master's Thesis Summary

Master's Thesis Summary

- **Title** : Design and Evaluation for Click Feedback of Vibrotactile Display in Automotive Environment
- **Motivation**

  - Nowadays, many infotainment systems are used in vehicles while driving, which may significantly decrease driving safety.
  - Haptic Feedback on the touch screen may be a solution.
  - Need to study on designing and perceptual evaluation of click feedback on vibrotactile display in Automotive Environment

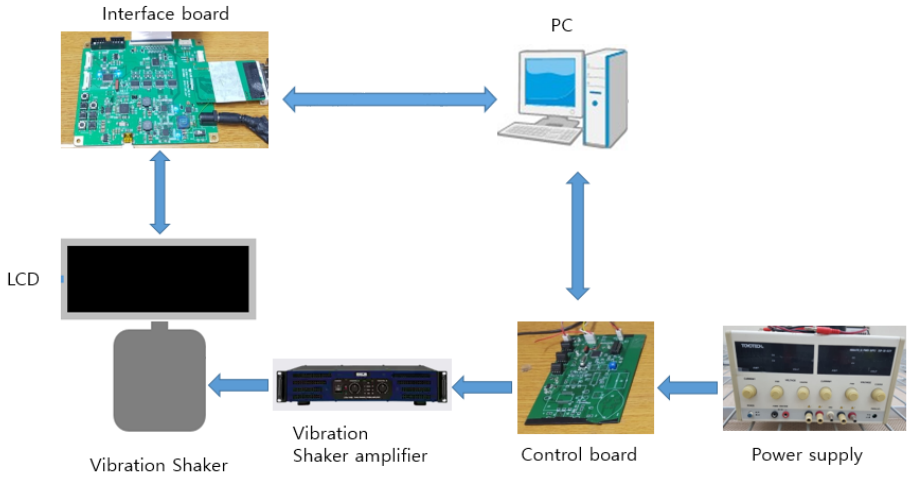
- **Contribution**

  1. Design the preferred click feedback signal on vibrotactile display

  2. Investigate the Detection Threshold and Just Noticeable Difference value of click feedback at the vibration direction of In-plane and Out-of-plane in Automotive Environment

  3. Investigate the Detection Threshold of click feedback at the vibration direction of Out-of-plane in Ambient Vehicle Vibration

Vibrotactile Perception



System Block Diagram

	In-plane	Out-of-plane
Construction		
Experiment		
Click Feedback direction	Lateral to fingertip	Normal to fingertip

Vibration Direction

Objective	Investigate the most preferred Click Feedback to use in Perceptual study
Question	Which button (A, B) do you prefer as a Click Feeling?
Graphic User Interface & Click feedback Signal	
Click feedback Signal	Frequency(80, 120, 180, 270Hz [9]) x Duration(1, 2cycle) x Waveform(sine, square) = 16 signals Vibration acceleration : 3G (Times as Gravitational acceleration)
Method	Pair-wise comparison method
Session Configuration	2 sessions, Each sessions : 120 trials (16C2) Each Click feedback - 30 times

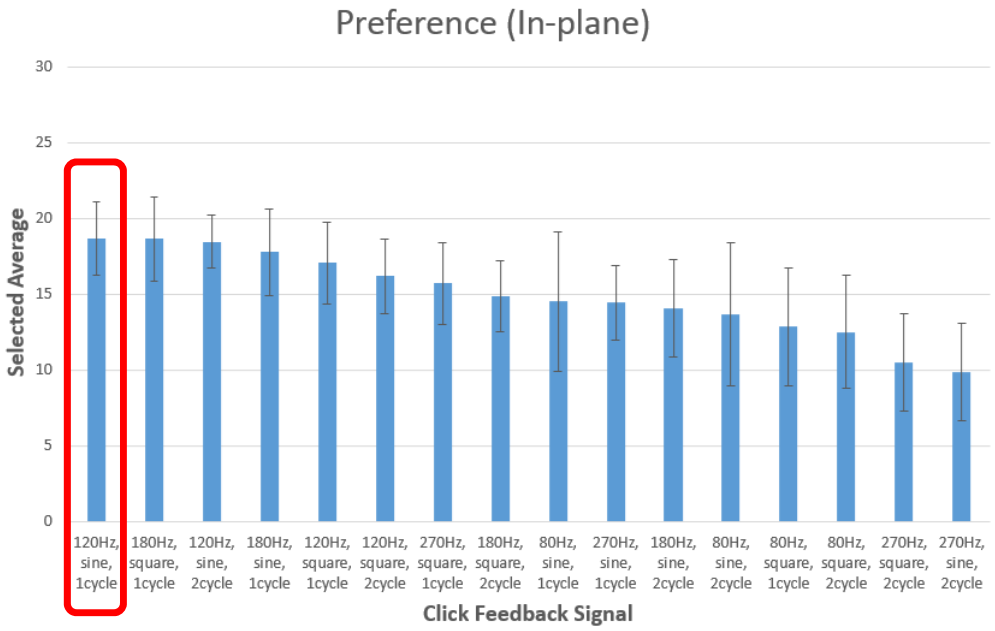
Preference Study Procedure

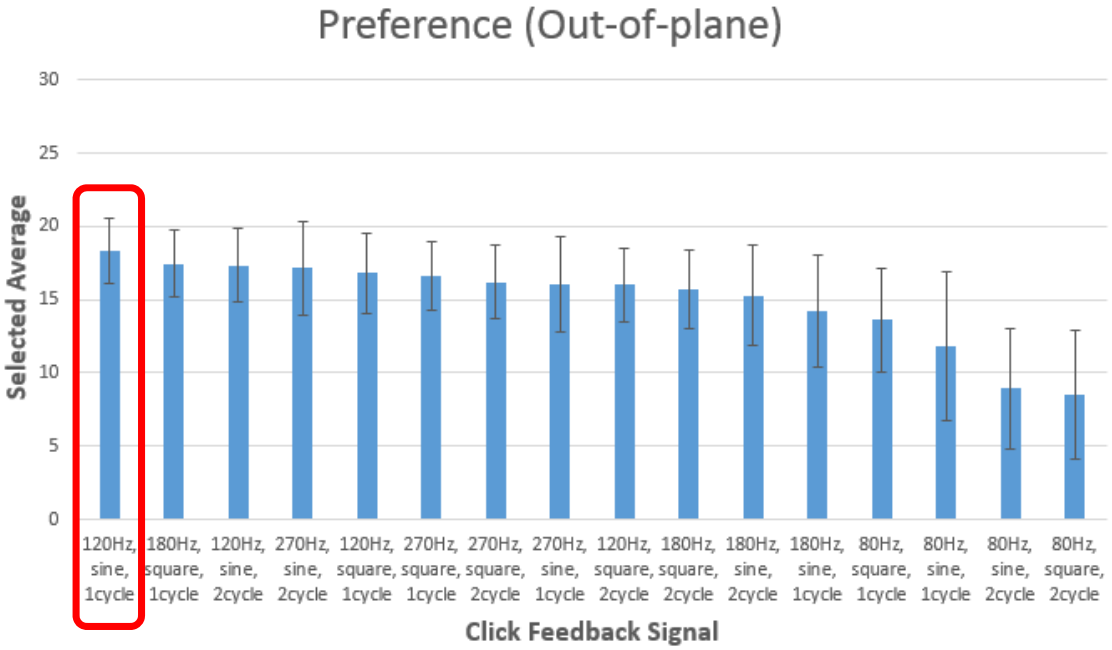
	Detection Threshold	Just Noticeable Difference
Objective	For investigating perception of smallest click feedback	For investigating perception of smallest difference for click feedback
Question	Which button(A, B) is more intensive?	Which button's (A, B, C) intensity is different?
Graphic User Interface		
Paradigm	Two-alternative forced-choice paradigm [10]	Three-alternative forced-choice paradigm [10]
Method	One up/Two down adaptive staircase method [11]	
Stimulus Amplitude (Acceleration)	Reference : 0.1G_{rms} (vehicle vibration) Start : 1G (vehicle vibration + Click feedback)	Reference : 3G (vehicle vibration + Click feedback) Start : 6G (vehicle vibration + Click feedback)
Frequency	80, 120, 180, 270Hz [9]	

Perceptual Study Procedure

Preference Study for Click Feedback

- Results



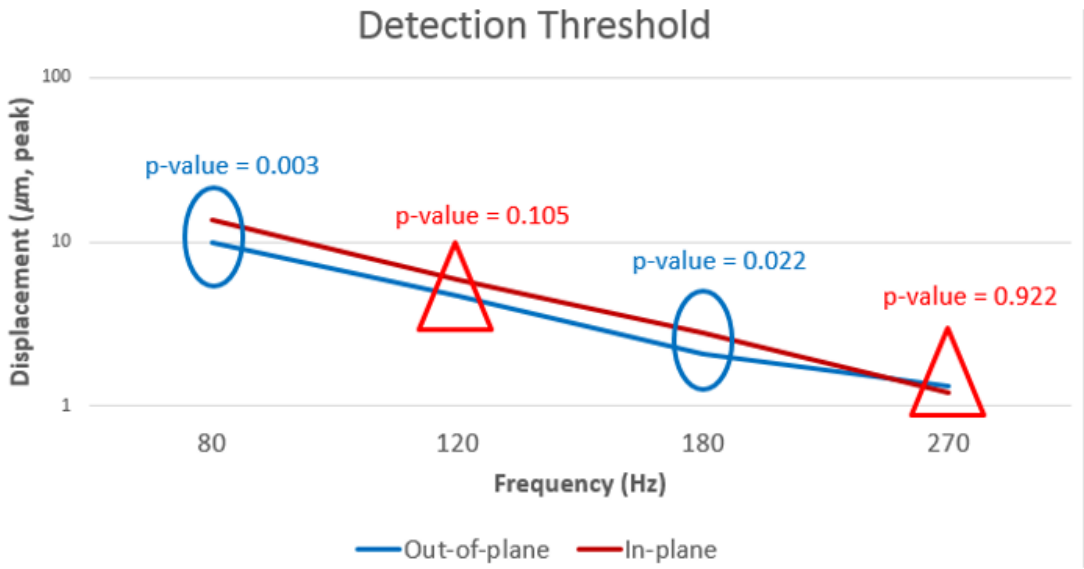


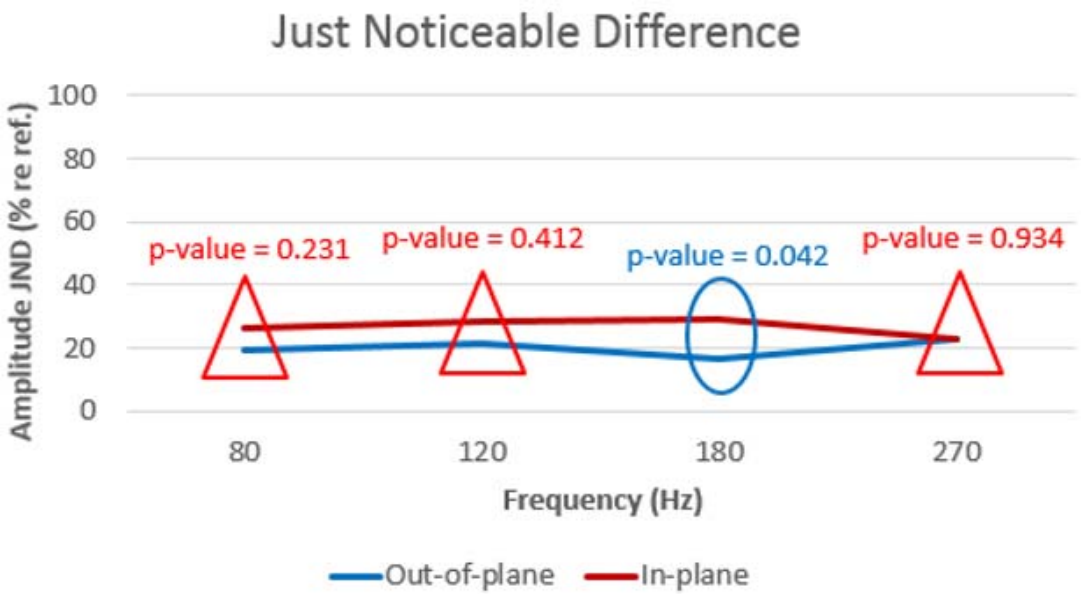
- Most Preferred Click feedback signal - 120Hz, sine, 1cycle

Perceptual Study for Click Feedback

1. Evaluation of perception for the In-plane and Out-of-plane of Click feedback in Automotive Environment

- Results



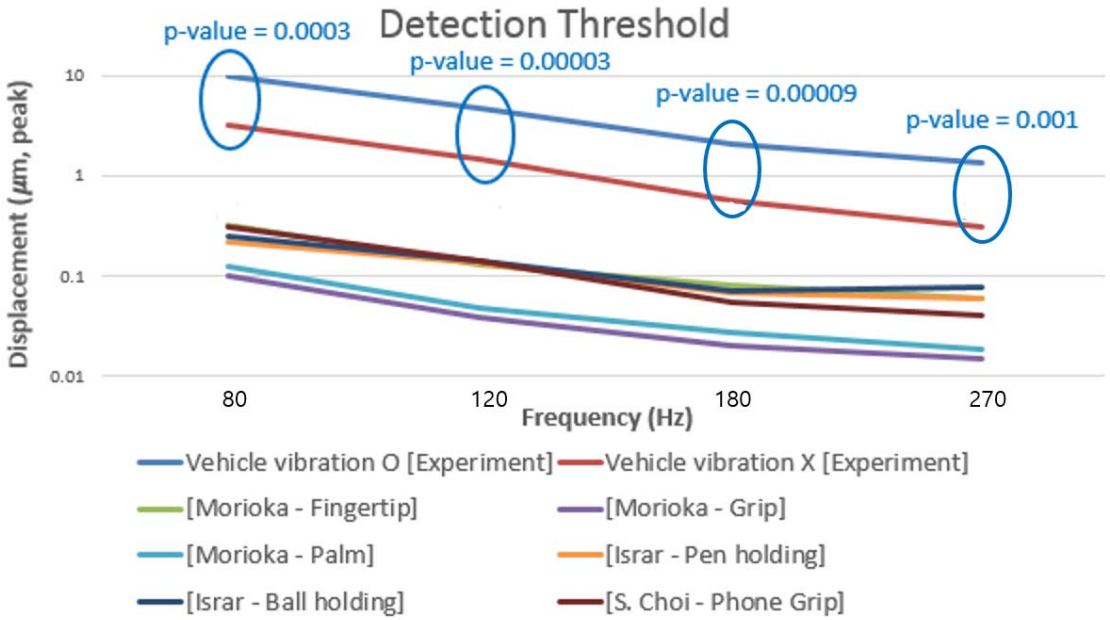


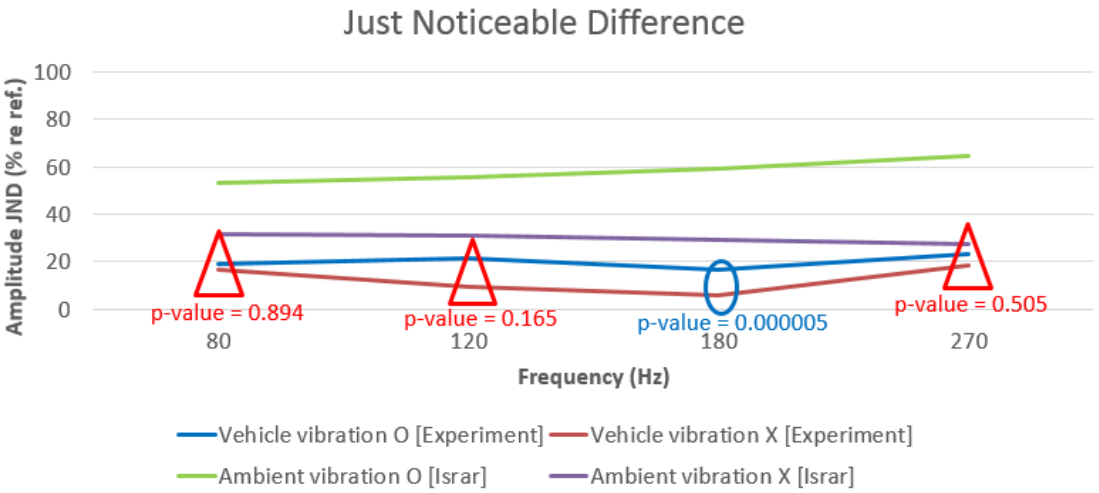
- In 180Hz, DT, JND value (0.7μm, 12.3%) is lower in Out-of-plane than in In-plane.
- **Conclusion** : people have more sensitive detection and discrimination for out-of-plane click feedback of 180Hz rather than In-plane click feedback of 180Hz.

Perceptual Study for Click Feedback

2. Evaluation of perception for ambient vehicle vibration in Out-of-plane Click feedback

- Results





- DT value in the vehicle vibration was measured to be 1 – 6.6μm higher.
- **Conclusion** : When the out-of-plane click feedback is offered, people would be dull to detect a click feedback in the ambient vehicle vibration.

Industrial Project Summary

Industrial Project Summary

- **Title** : Development of Automotive Haptic Display Module using VCM / POLED

- **Motivation**

  - Investigating the Feasibility of Localized Haptic Feedback based on Bending wave haptics

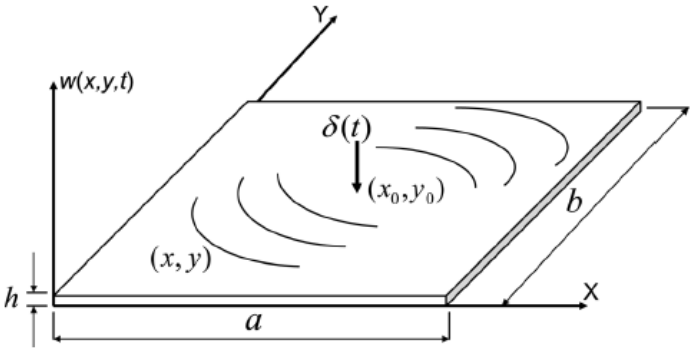
- **Contribution**

  - Design the Procedure of Bending Wave Haptics system (in Both Glass plate and Industrial Display panel)

  - Investigate Localization Quality of Localized Haptic Feedback depending on Boundary Condition
    (Characterization of Voice coil motor, FEM model construction, Research on Optimal Boundary Condition)

Bending Wave Haptics Theory

- Bending wave equation



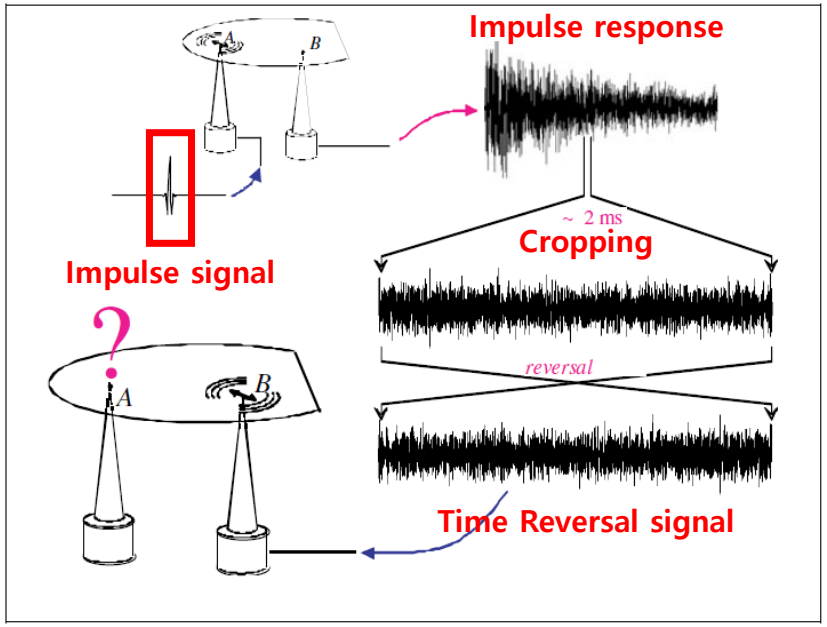
$$(D\nabla^4 + \rho h\frac{\partial^2}{\partial t^2})w(x,y,t) = \delta(t)\delta(x-x_0)\delta(y-y_0)$$

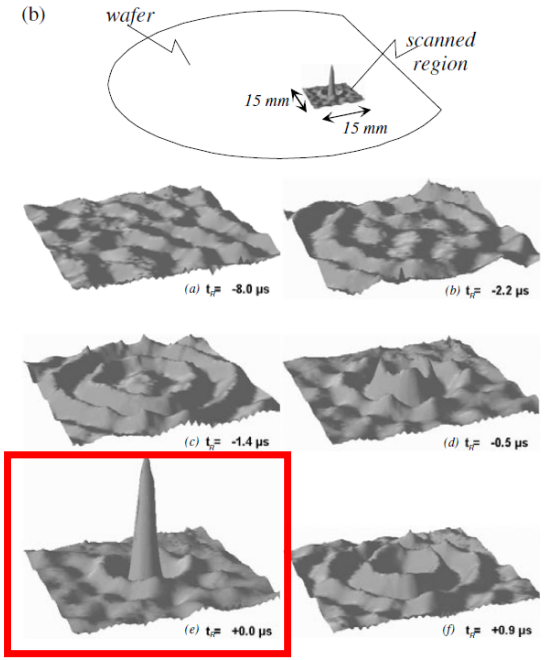
$$D = \frac{Eh^3}{12(1-v^2)}$$

$$\omega_{mn} = \sqrt{\frac{D}{\rho h}\left[\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right]}$$

$$w(x,y,t) = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{4}{\omega_{mn}abh\rho}sin\frac{m\pi x}{a}sin\frac{n\pi y}{b}\times sin\frac{m\pi x_0}{a}sin\frac{m\pi y_0}{b}\sin(\omega_{mn}t)$$

Time Reversal Wave Localization





Reference 1 : Impact localization combined with haptic feedback for touch panel applications based on the time-reversal approach, J. Acoustic. Soc. Am., Vol. 129, No. 3, 2011
Reference 2 : Acoustic time-reversal mirrors, Institute of Physics Publishing, 2001

Bending Wave Haptics Theory

- Bending wave equation

Time Reversal Wave Localization

1. Contrast : Focused amplitude / other amplitude, Localization quality

$$C = \sqrt{BT_c}\sqrt{\frac{Q\tau[1-\exp(-2T/\tau)]}{(Q+1)\tau[1-\exp(-2T/\tau)]+T_c}}, \qquad T_c = \frac{\sqrt{3}S}{e}\sqrt{\frac{\rho(1-\nu^2)}{Y}},$$

2. Amplitude : Out-of-plane displacement

$$A \propto Q\tau[1-\exp(-2T/\tau)]$$

3. Resolution : Spatial resolution (Size of the focusing spot at half maximum amplitude)
   Temporal resolution (Duration at half maximum amplitude of focusing spot)

$$R_s \simeq \frac{\lambda_{\min}}{2}, \qquad R_t \simeq \frac{1}{2f_{\max}}, \qquad \frac{R_s^2}{R_t} = \frac{\pi}{\sqrt{12}}e\sqrt{\frac{Y}{\rho(1-\nu^2)}}$$

4. Repetition : to repeat focusing process to obtain calibrated impulsive displacements

$$T_r \geq \tau \qquad \hat{C} = C\sqrt{1-e^{-2Tr/\tau}}$$

5. Energy Balance : energy needed to achieve focusing at one point

$$E = \frac{\pi^3}{18}\frac{Y}{1-\nu^2}e^3\left(\frac{A}{R_s}\right)^2.$$

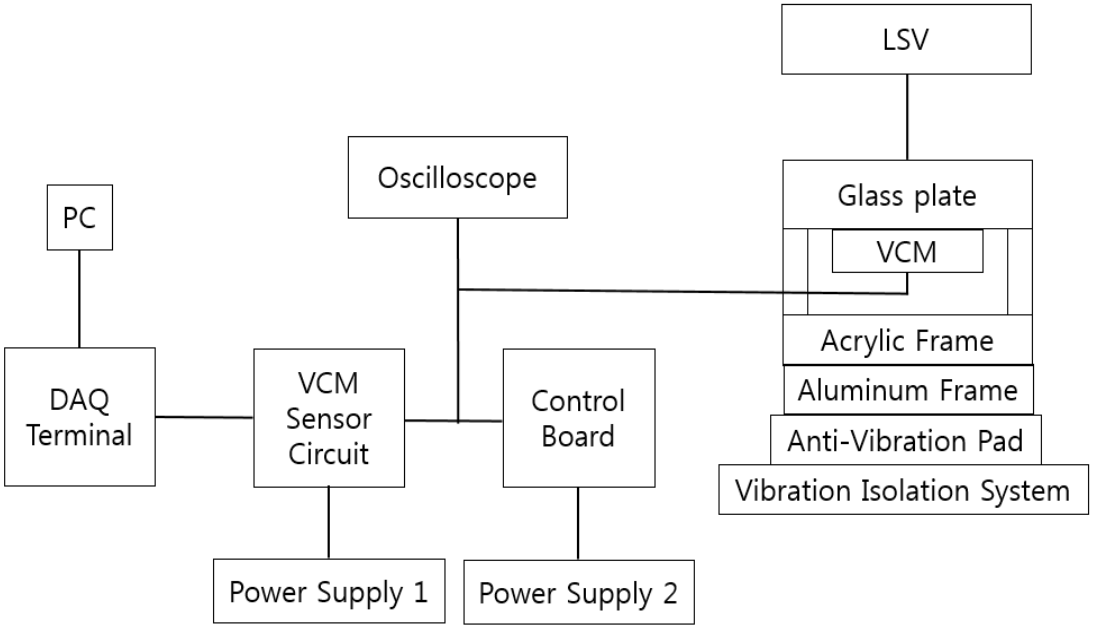
Q = number of transducers
B = bandwidth of driving signal
T = duration of focusing process
T_r = focus repetition period
τ = attenuation time constant of vibration
T_c = plate time constant
R_s = spatial resolution
R_t = Temporal resolution
$\lambda_{\min}$ = shortest wavelength
ρ = plate density
Y = plate Young's modulus
υ = plate poisson's ratio
e = plate thickness
S = plate surface area

Reference 3 : Localized Tactile Feedback on a Transparent Surface through Time-Reversal Wave Focusing, IEEE TRANSACTIONS ON HAPTICS, VOL. 8, NO. 2, 2015

Time Reversal Wave Localization

- Experimental setup

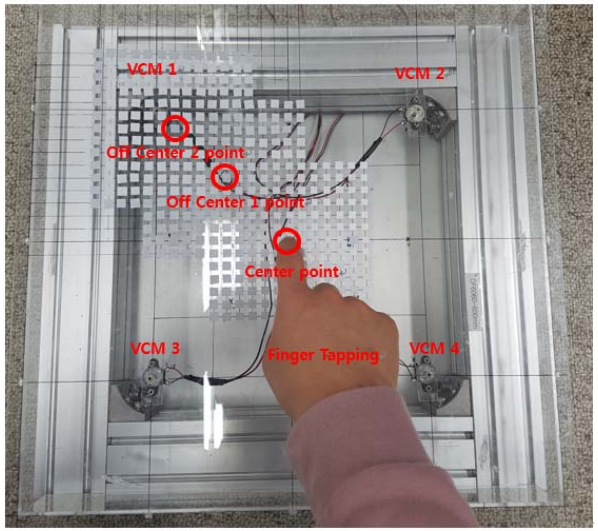
System Configuration



System Block Diagram

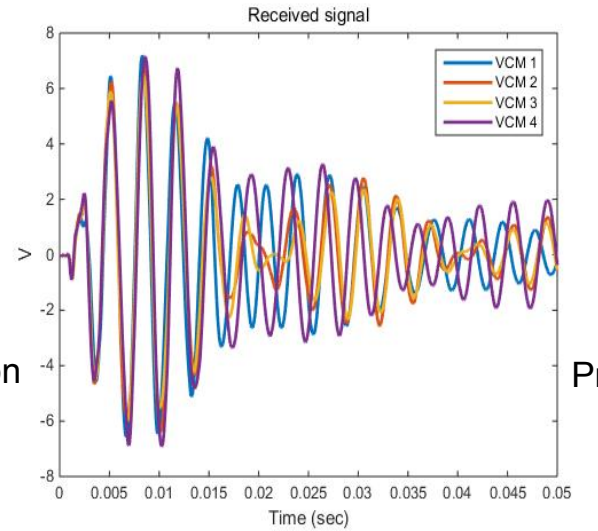
Time Reversal Wave Localization

- Procedure



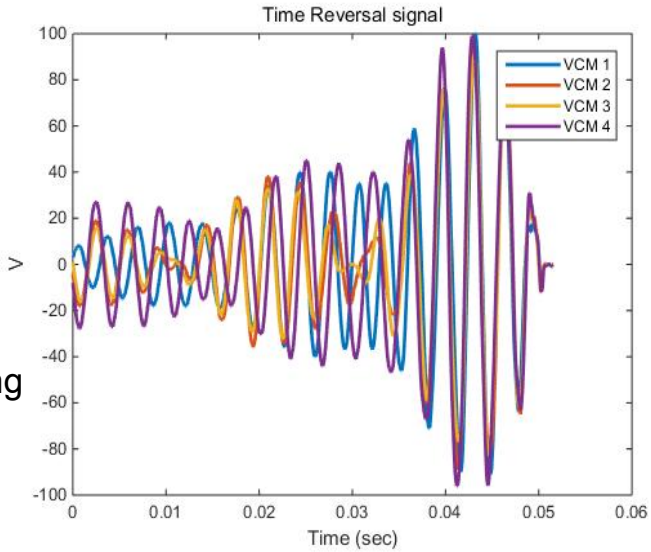
Impulse response acquisition

Data Acquisition



Impulse response signal

Signal Processing

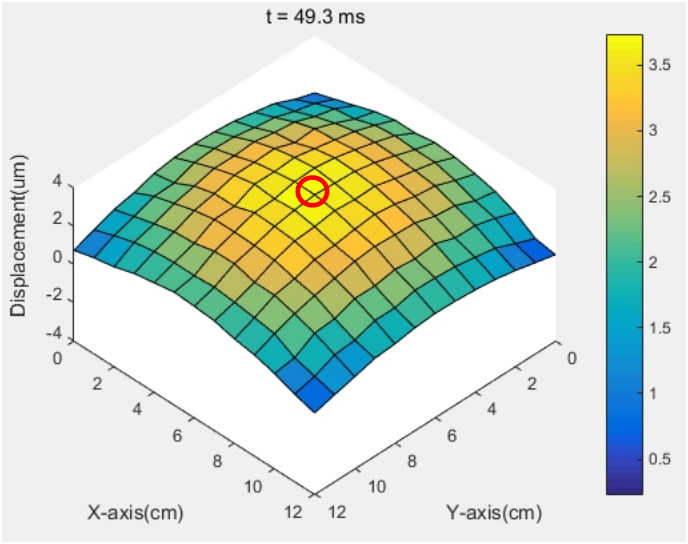


Time Reversal signal

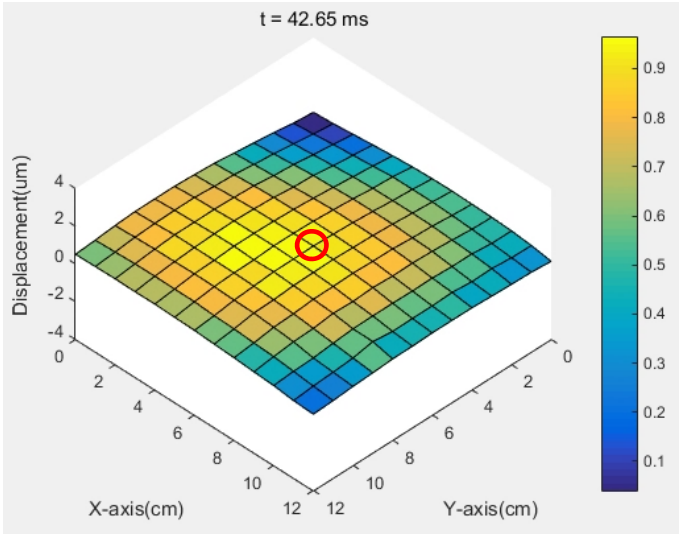
Time Reversal Wave Localization

1. Evaluation in Symmetric Boundary Condition

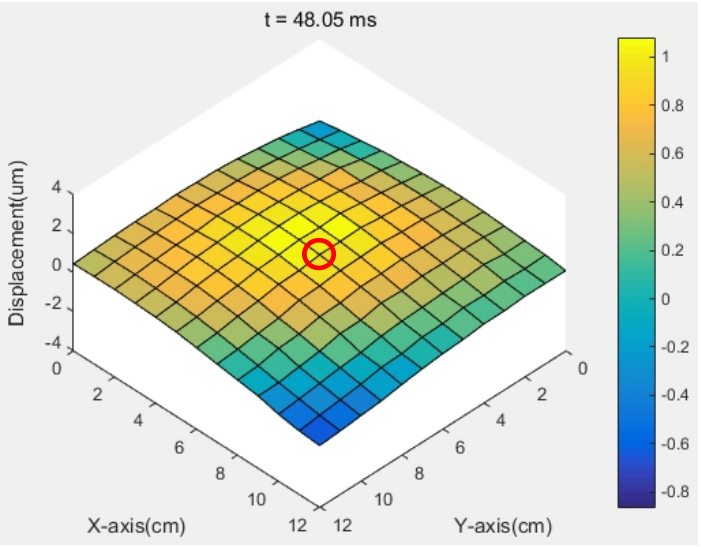
(1) Time Response



Center point



Off Center 1 point



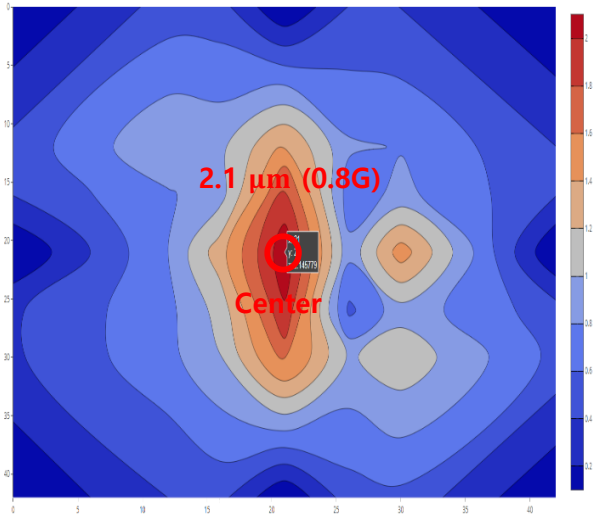
Off Center 2 point

- As far from Center point, Peak Displacement is measured to be low (3.7 – 1 μm)
- Meaningful Localization (DT : 1 μm)

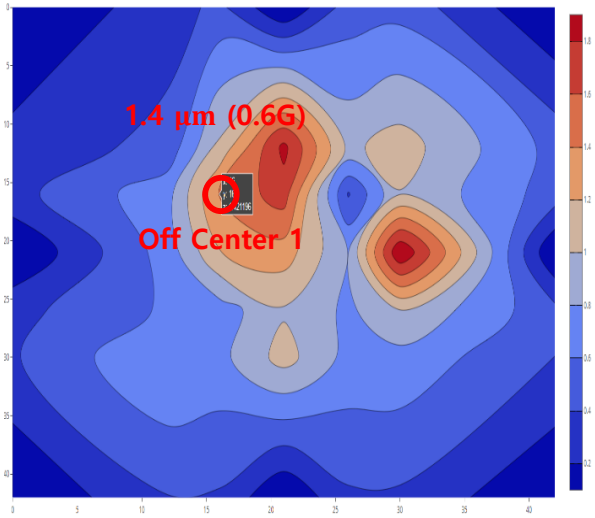
Time Reversal Wave Localization

1. Evaluation in Symmetric Boundary Condition

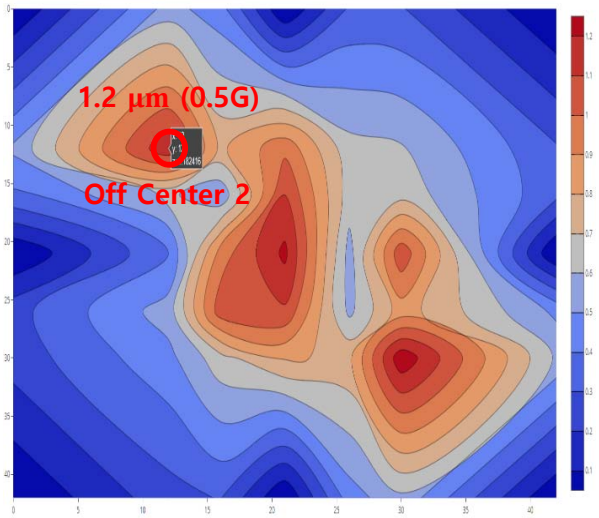
(2) Peak Response



Center point



Off Center 1 point



Off Center 2 point

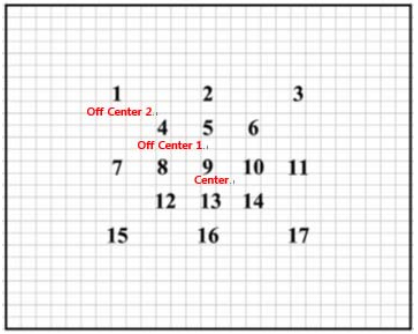
- As far from Center point, Peak Displacement is measured to be low (2.1 – 1.2 μm)
- Meaningful Localization (DT : 1 μm)

Time Reversal Wave Localization

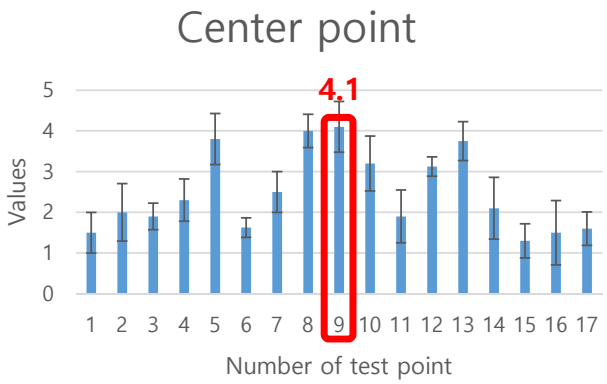
1. Evaluation in Symmetric Boundary Condition

(3) Haptic Feedback User Study

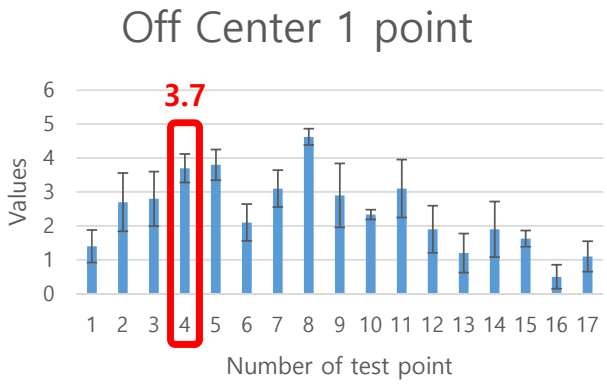
- Localization value : 0 - 5



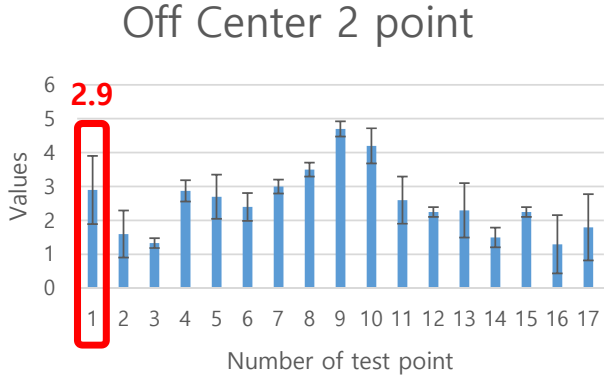
Test point



Center point



Off Center 1 point



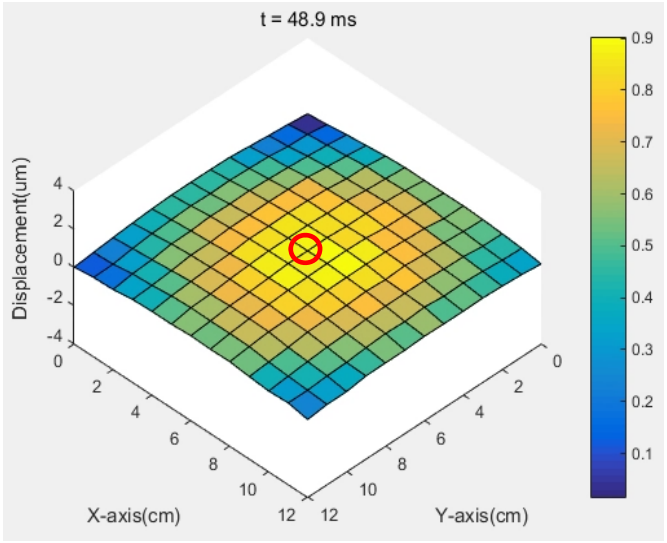
Off Center 2 point

- As far from Center point, Localization value is going low (4.1 – 2.9)
- **Preliminary Conclusion** : Off Center point has a bad Localization Quality compared to Center point

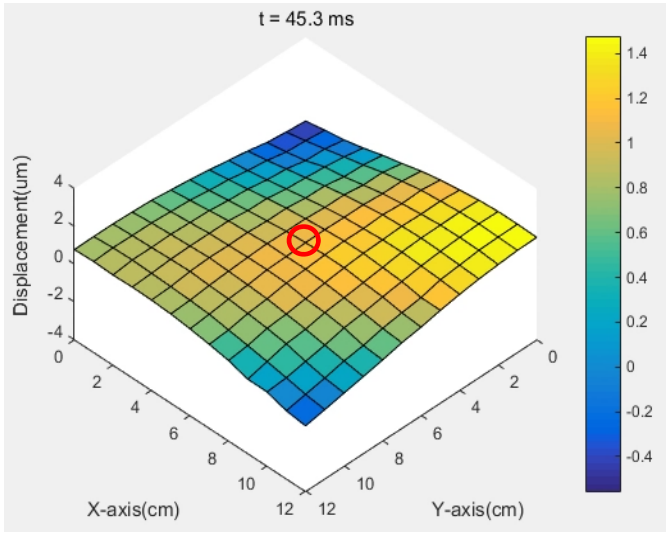
Time Reversal Wave Localization

2. Evaluation in Asymmetric Boundary Condition

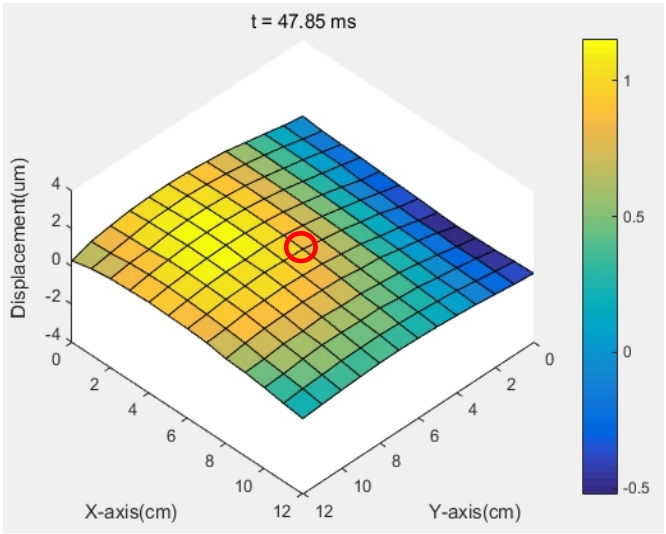
(1) Time Response



Center point



Off Center 1 point



Off Center 2 point

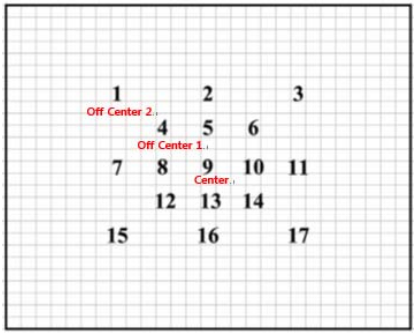
- Regardless of Localization point, Uniform Peak Displacement (0.9 – 1.4 μm)
- **Preliminary Conclusion** : Uniform Localization Quality compared to Symmetric Boundary Condition
  Low Localization Accuracy compared to Symmetric Boundary Condition

Time Reversal Wave Localization

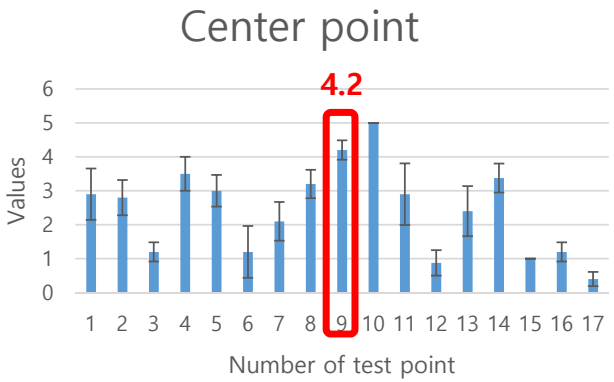
2. Evaluation in Asymmetric Boundary Condition

(2) Haptic Feedback User Study

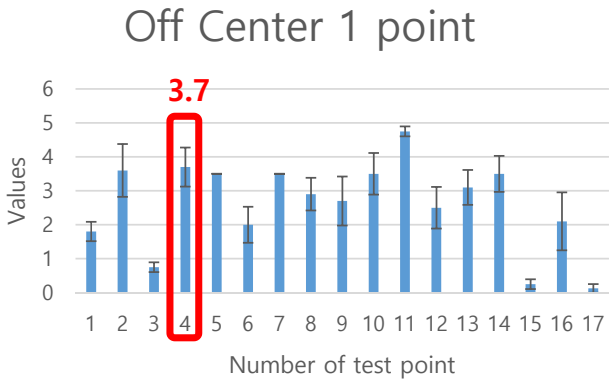
- Localization value : 0 - 5



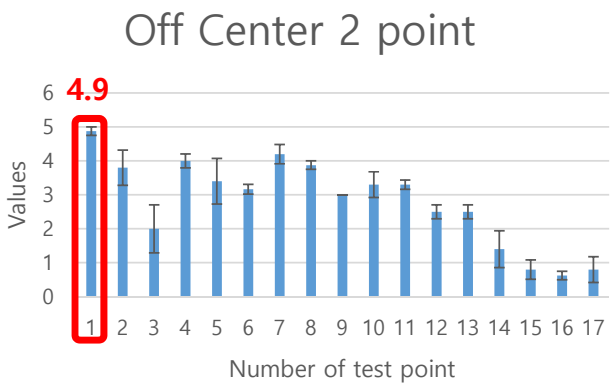
Test point



Center point



Off Center 1 point

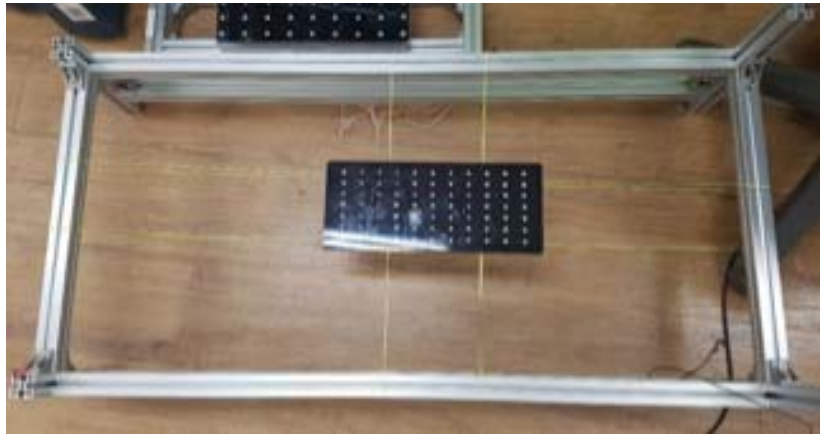


Off Center 2 point

- High Localization value at the Off Center 2 point

Time Reversal Wave Localization

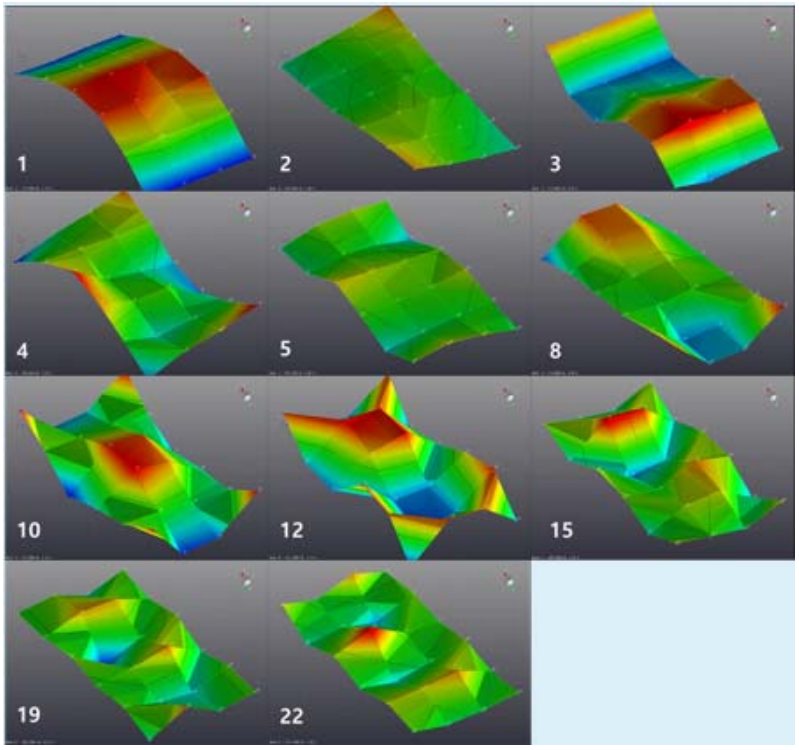
- Display panel FEM model



Impact Hammering Test

Mode (Observed)	1	2	3	4	5	8	10	12	15	19	22
Frequency (Hz)	116.5	163.4	312.6	346.6	593.2	713.5	910.3	1212.0	1579.8	1920.0	2214.0

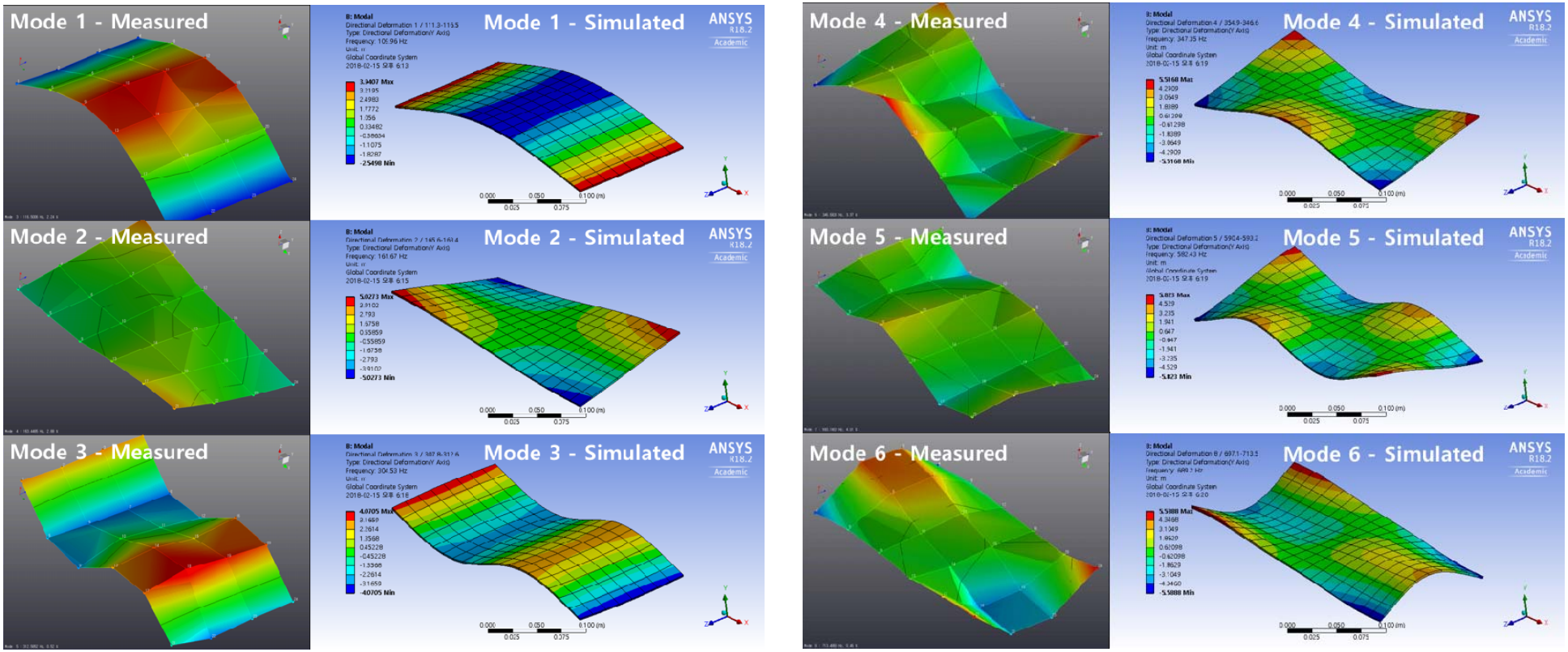
Modal frequency



Mode shape

Time Reversal Wave Localization

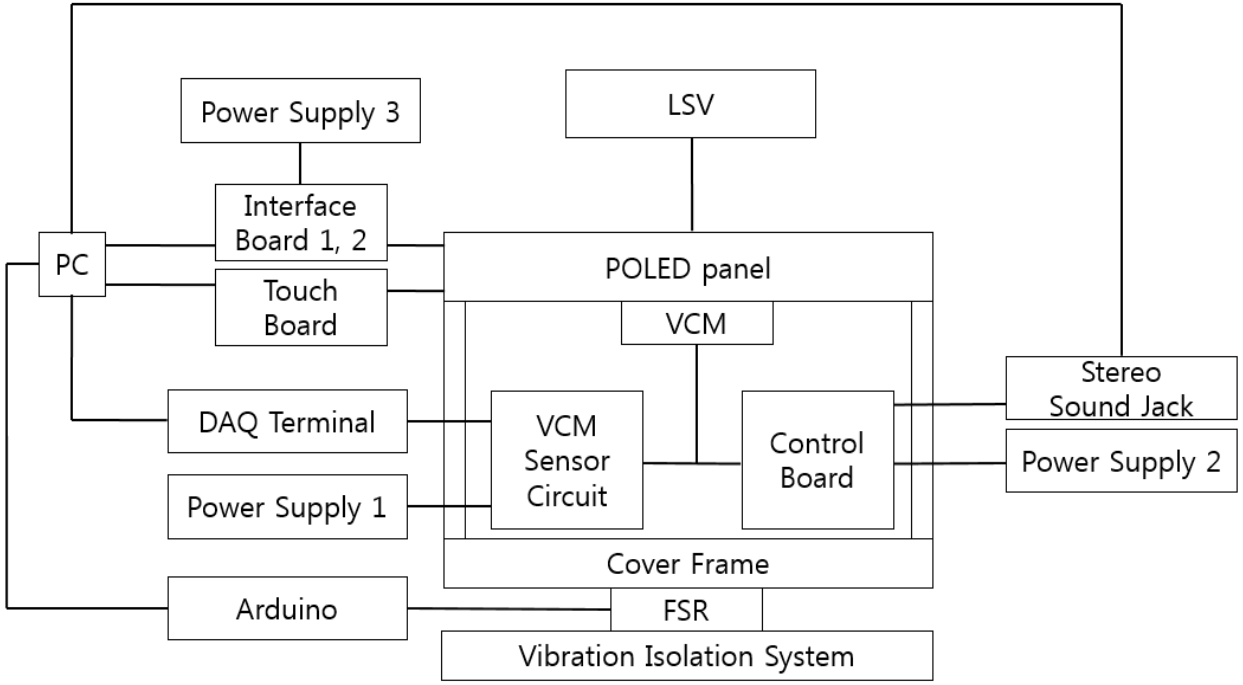
- Display panel FEM model Comparison



Time Reversal Wave Localization

- Sample Development

System Configuration



System Block Diagram

Time Reversal Wave Localization

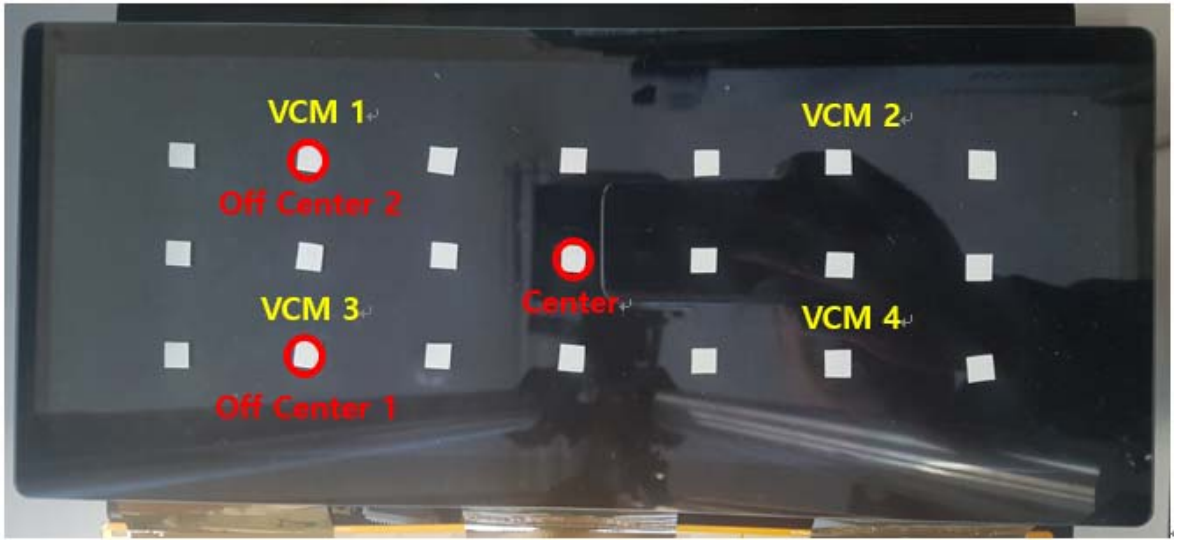
- Sample Development

System Inner Composition

Impact Localization measurement
(Laser Vibrometer)

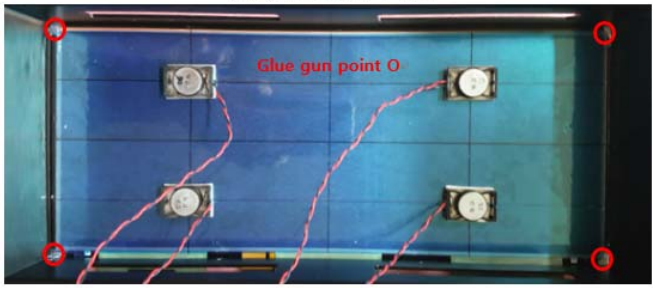
Time Reversal Wave Localization

- Sample Development

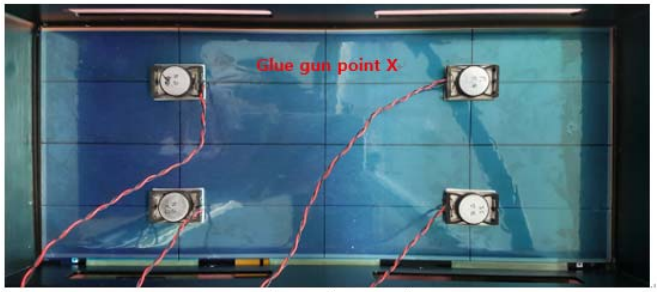


Impact Localization point and Actuator attachment

< 4 Edge Point 글루건 부착 >



< 4 Corner Point 글루건 부착 >



< 4 Edge Simply Supported >

Boundary Condition

Time Reversal Wave Localization

- Sample Development

- Investigation on Optimal Boundary Condition based on Localization Quality and Haptic Feedback

➔ **4 corner attachment**

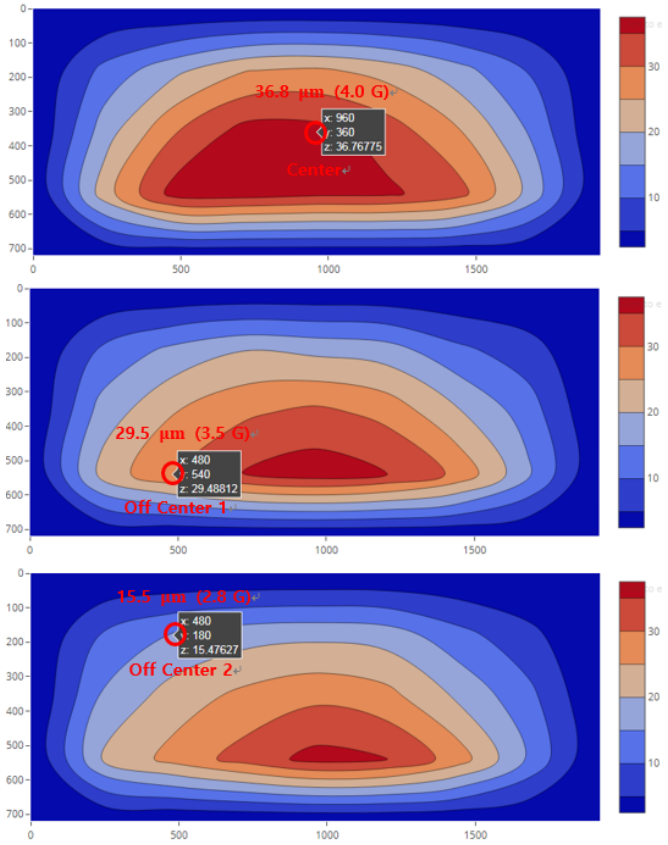
Contrast (Ratio) (Impact Localization Quality)	Boundary Condition A (4 edge point 부착)	Boundary Condition B (4 corner point 부착)	Boundary Condition C (Simply Supported)
Center	1.4	1.4	1.6
Off Center 1	1.4	1.8	1.8
Off Center 2	0.8	1.8	1.9
평균	**1.2**	**1.7**	**1.8**

진동가속도 (G) (Haptic Feedback Quality)	Boundary Condition A (4 edge point 부착)	Boundary Condition B (4 corner point 부착)	Boundary Condition C (Simply Supported)
Center	4.0	3.0	3.1
Off Center 1	3.5	4.9	2.1
Off Center 2	2.8	5.2	3.9
평균	**3.4**	**4.4**	**3.0**

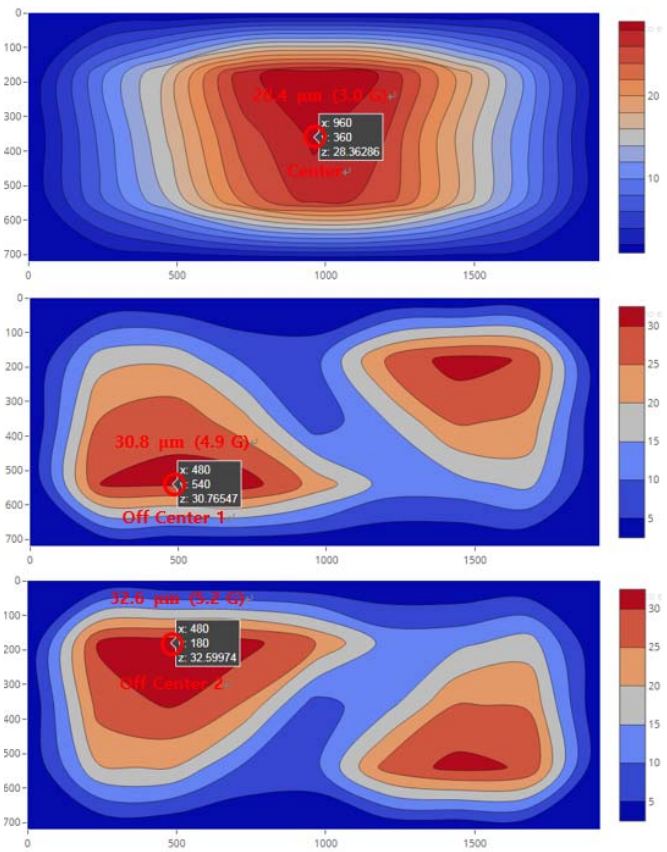
Impact Localization Result on Different boundary conditions

Time Reversal Wave Localization

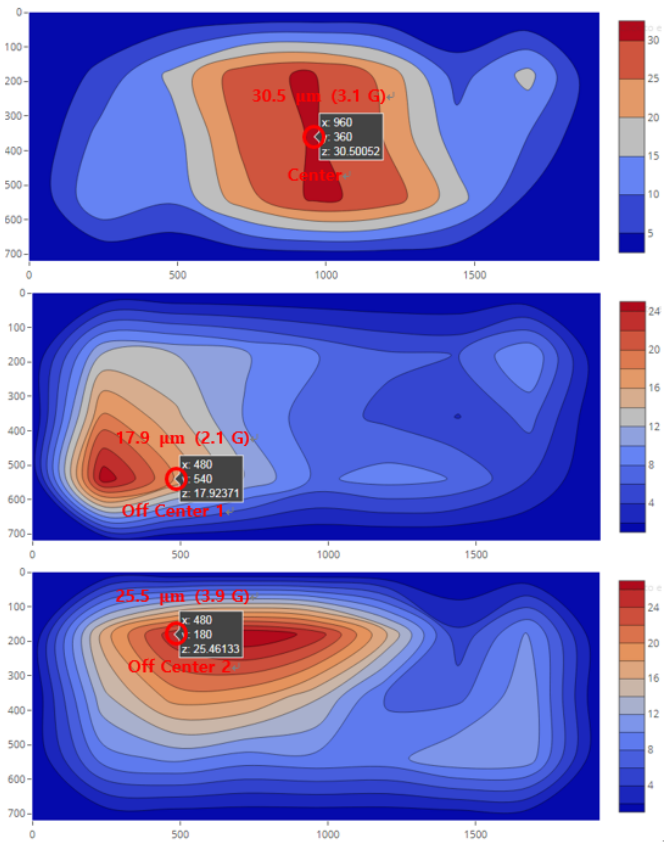
- Peak Response



4 edge point 부착



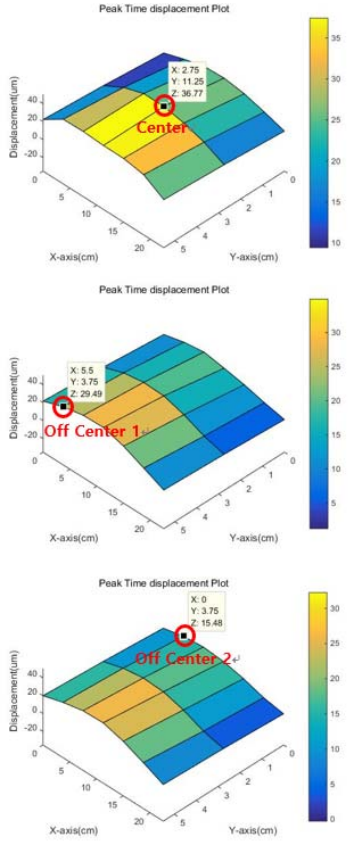
4 corner point 부착



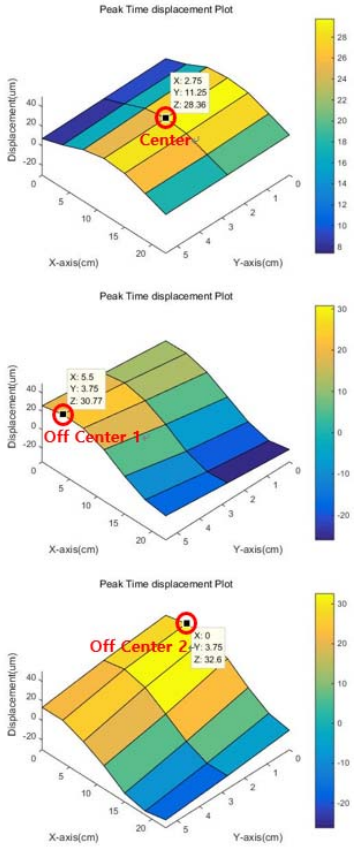
Simply Supported

Time Reversal Wave Localization

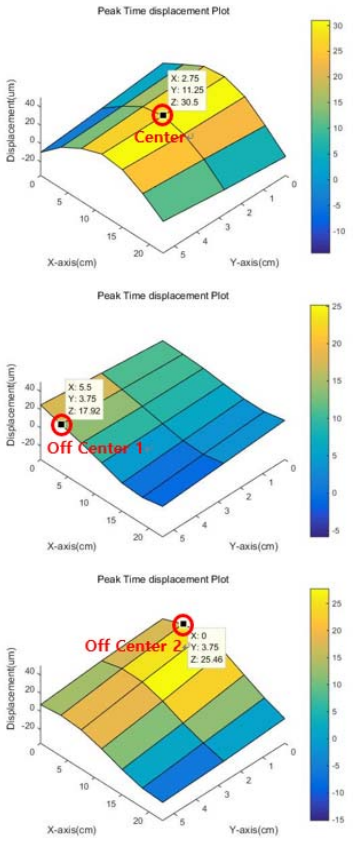
- Time Response



4 edge point 부착



4 corner point 부착



Simply Supported