VibEye: Vibration-Mediated Object Recognition for Tangible Interactive Applications

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Outline

- Background
- Introduction
- System Design and details
- Evaluation
- Conclusion

Context-rich Digital Augmentation

- Context-rich digital augmentation is crucial to couple digital and physical worlds in the era of virtual reality

- One key challenge is the absence of comprehensive sensing methods

- Various studies are on-going regarding the ways for computing devices to recognize the context of use
  - e.g., location, object and its state, user’s action, and material

Material Recognition

- Sensing methods for material recognition utilize various physical channels including photic, electromagnetic, acoustic, and vibratory

Sensing methods	Properties
Light	• Require a flat surface for suitable light reflection • Hard to recognize the objects with complex material composition or arbitrary shape • Not suitable for querying the invisible aspects of objects such as weigh, stiffness, damping, and internal structure
Electromagnetic	• Classify various objects such as body parts, transparent materials, and so on • Only applicable to the objects that emit electromagnetic waves
Acoustic	• Trigger an external signal to an object which is similar to vibration-based, but it uses broader frequency range • Detect the state changes because acoustic waves are sensitive but weak

Vibration-based Sensing

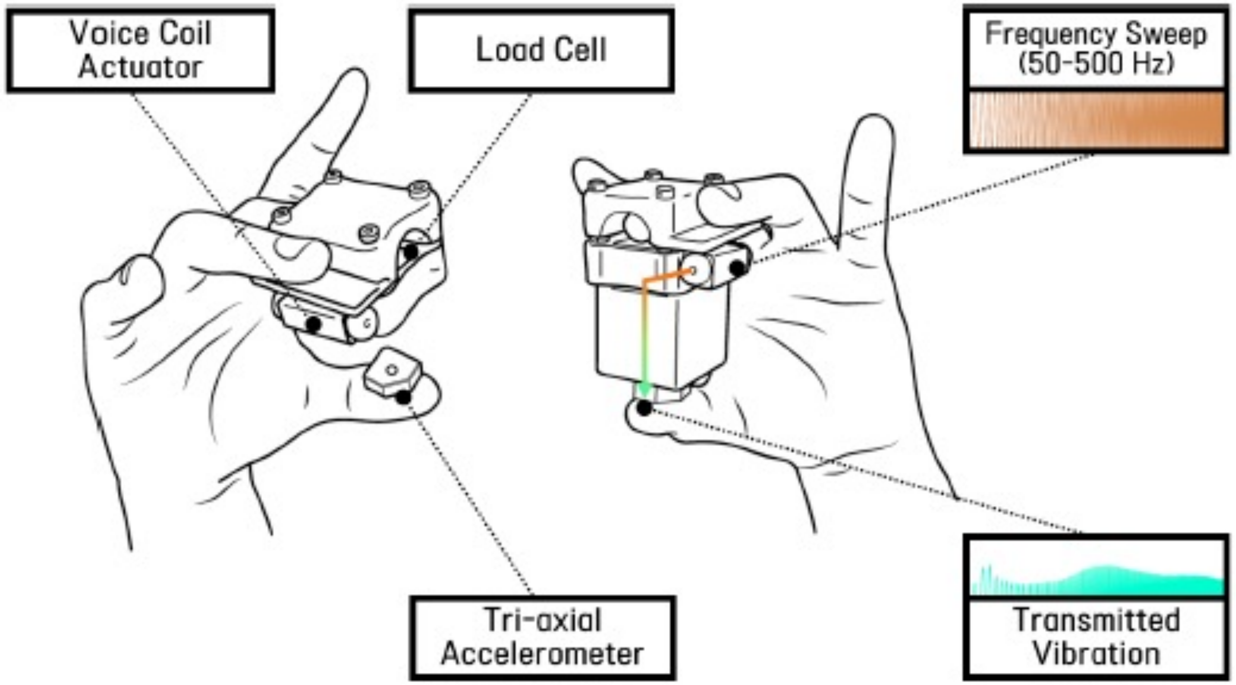
- When a mechanical vibration propagates through a medium, it leaves a unique signature
- Active object sensing is to detect the patterns of vibrations emanating from an object (e.g., motor-powered vibrating objects)
  - It is useful, but it does not work for still objects
- Passive object sensing is to apply a structured vibration (e.g., sinusoidal frequency sweep) to a static object and measure the response
  - It compares the input and output signals for object recognition
  - The approach can be applied to any objects, but it requires an external vibration source

Vibration Data Processing Methods

- Signal processing mostly includes frequency domain analysis for feature extraction
  - It is usually calculated using FFT (Fast Fourier Transform) or STFT (Short-Time Fourier Transform) for acceleration measurements
- Feature extractions commonly have complex feature selection and computation
- PCA (Principal Component Analysis) can be applied to reduce the feature dimensions
  - The proposed system is applied much simpler way with spectrogram and PCA

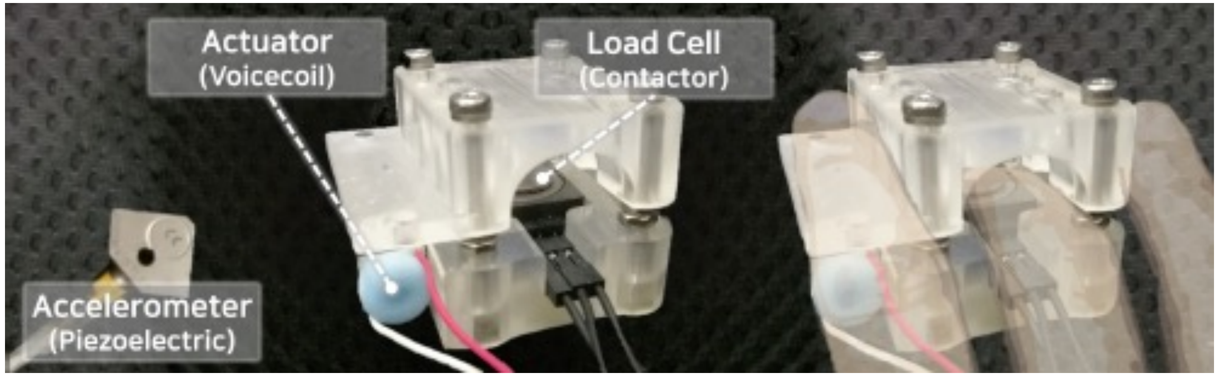
Introduction: VibEye

- The paper presents VibEye: a vibration-mediated recognition system of objects for tangible interaction
- Vibration can be represented to a spectrogram which is used for classification as the image inputs
- The system is able to overcome difficulties of object recognition by light and sound



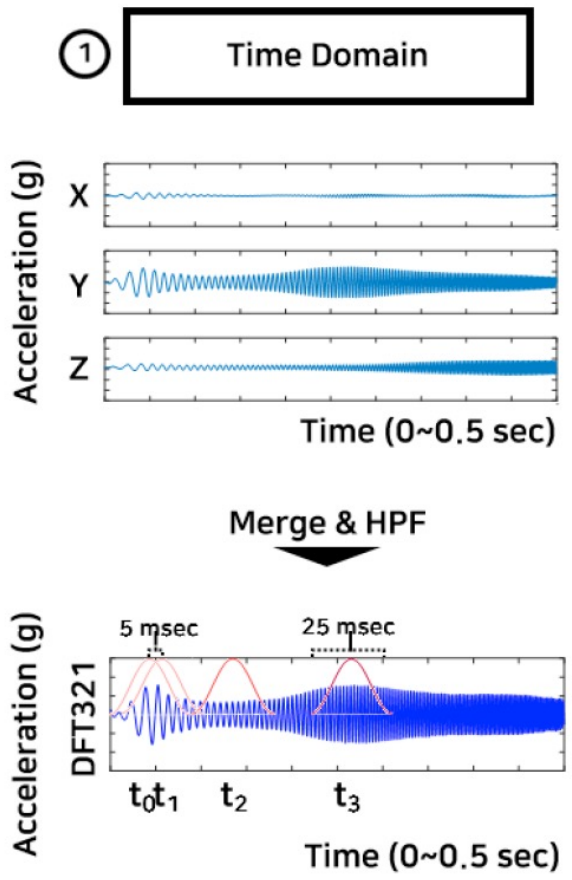
Hardware Design

- The prototype is designed to support object grasping by pinching
  - A voice coil actuator is attached to the bottom part for generating vibration
  - A load cell is put inside the place of the middle finger to measure active pressing force
  - An accelerometer is attached to the thumb's pad for sensing the vibration which is propagated through the object



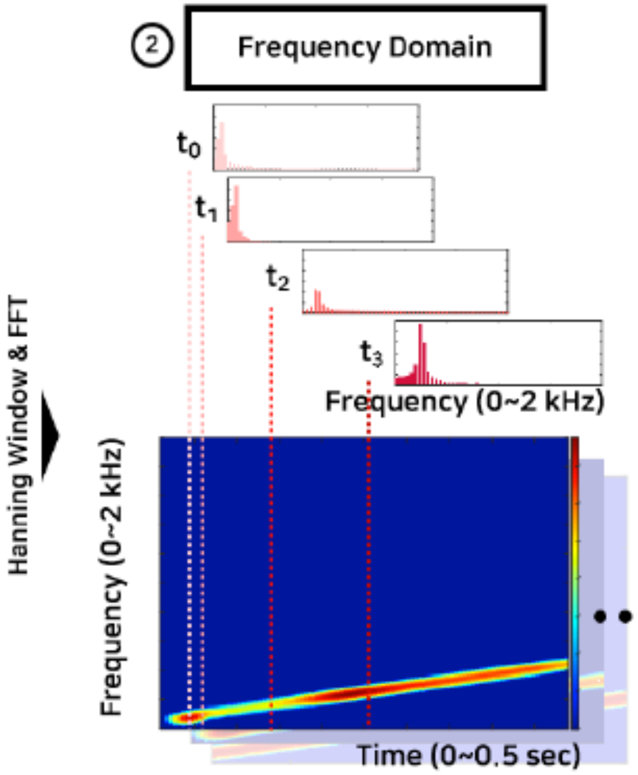
Step1: Data Sensing and Preprocessing

- The system produces a sinusoidal vibration based on sinusoidal frequency sweep during 0.5 sec
- It merges the three orthogonal signals to reduce the effects of hand's orientation changes
- DFT321 (Discrete Fourier Transform) is used to maximize both temporal and spectral similarity
- High-pass filter (HPF) is applied to remove the effects of low-frequency hand motion using a Chebyshev type-2 filter



Step2: Spectrogram Computing

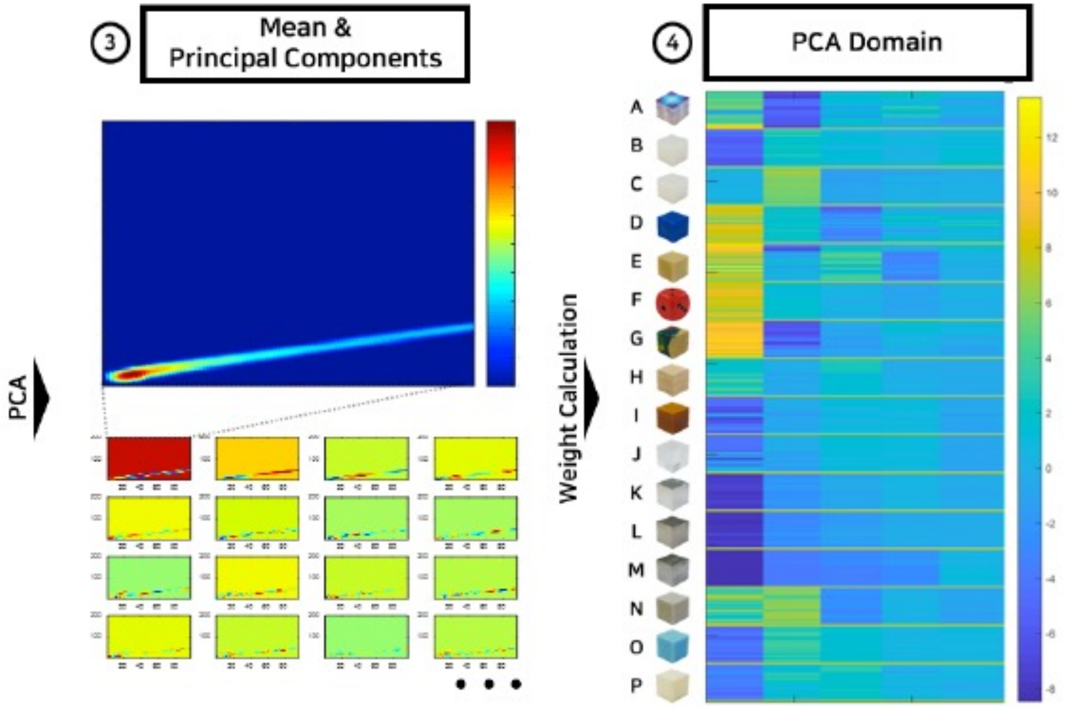
- The output signal is segmented to a sequence of 96 short signals by sliding a 0.025 s long Hanning window
- Every segment is stacked along the time to construct a single image of spectrogram after applying 2048-DFT
- The raw spectrogram is normalized by removing the values lower than a cutoff level δ to suppress noise and transients
- The final spectrogram is unique enough to identify objects like a signature for image-based classification



Step3: PCA and C-SVM

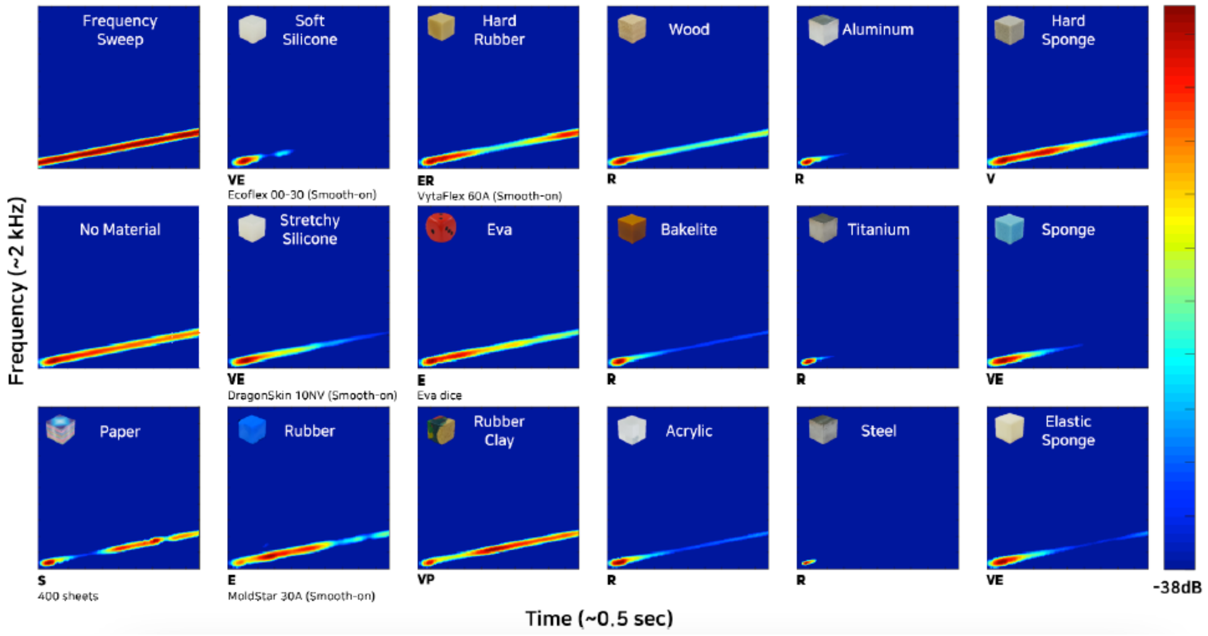
- PCA is applied to the spectrograms
  - It extracts the most discriminant features from the images in an unsupervised manner

- All the PCs of the spectrograms are fed to C-SVM (Classification Support Vector Machine) with a linear kernel to train a classifier



Sample Set

- Standard Objects
  - 16 standard objects are selected considering elasticity, viscosity, and weight
  - Objects are 35mm-long cubes
- Everyday Object
  - 25 objects of complex shapes and material compositions
  - Characteristics of objects include rigid, heavy, light, packaged, heterogeneous, homogeneous, etc.



Recognition Performance

- 320 spectrograms with standard objects were prepared as input images to PCA
- Cross-validation tests were conducted using C-SVM classifiers
  - It obtained more than 96% accuracy for 5-fold and 10-fold cross validation
- The most balanced classifier was at the 1:1 proportion (training and testing data) with 94.4% accuracy
- The computation performance is appropriate for tangible interaction because it only takes 31ms on average in Matlab

User Study – Standard Objects

- The user study was to test whether the classifier can recognize standard objects held in other users' hands
- 20 right-handed persons were participated in the experiment of standard objects
- It achieves 92.5% accuracy over all standard objects and participants
  - The bakelite (code I) and the acrylic cube (J) caused the performance drop because of the similarity

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A	Paper	97.5									2.5						
B	Soft Silicone		97.5													2.5	
C	Stretchy Silicone		2.5	92.5												5.0	
D	Rubber				100.0												
E	Hard Rubber	2.5				97.5											
F	Eva						100.0										
G	Rubber Clay	5.0						95.0									
H	Wood								100.0								
I	Bakelite									90.0	2.5	5.0	2.5				
J	Acrylic									67.5	32.5						
K	Aluminum											90.0	10.0				
L	Titanium											2.5	97.5				
M	Steel												2.5	97.5			
N	Hard Sponge														100.0		
O	Sponge		7.5													92.5	
P	Elastic Sponge																100.0

User Study – Everyday Objects

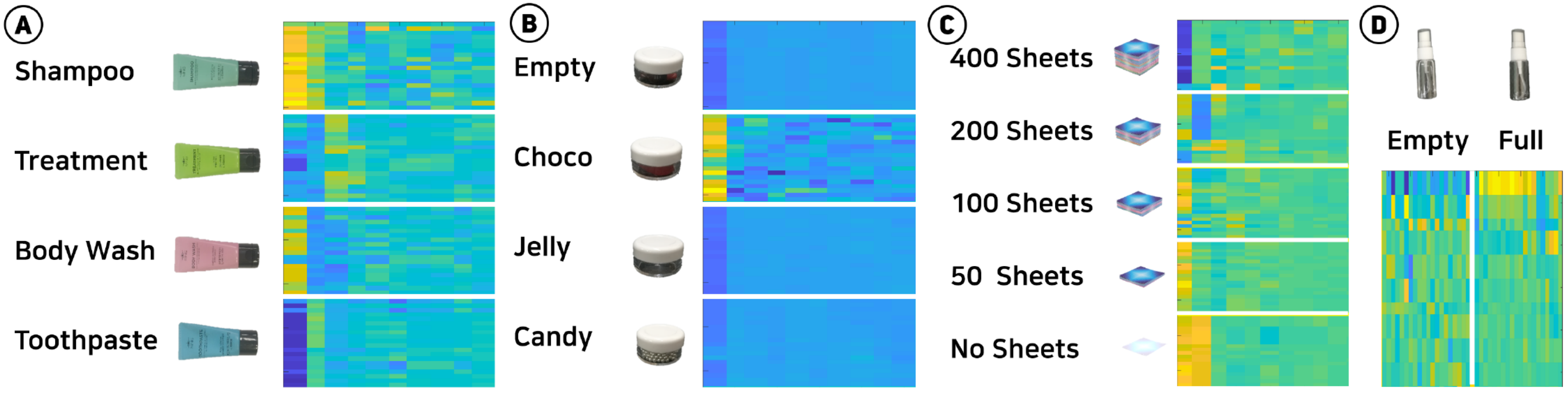
- The second experiment is to observe how the standard object classifier reacts to unseen everyday objects

Everyday Objects	Standard Object	Features
Wet sponge	B (soft silicone)	Elastic and viscous
Jelly; wrist pad; index (1st Phalanx); rubber ball; earplug	C (stretch silicone)	Very elastic and viscous
Two PU valls	D (rubber)	Highly elastic
Elastic eraser	F (eva)	elastic and little viscous
Wet glue	G (rubber clay)	viscous
Wooden plate	H (wood)	Wooden and rigid
Hard eraser; pen; small clock	E (hard rubber)	Light and rigid (Little elastic or buzzing)
Cosmetics	I & J (plastics)	Light and rigid
Mobile phone; perfume; multi-plug	L & M (metals)	Heavy and rigid

	A	B	C	D	E	F	G	H	I & J	K	L	M	N	O	P
Wet Glue	20.0						80.0								
Wet Tissue	32.5						67.5								
Toothpaste	57.5						35.0	7.5							
Wet Sponge		77.5	22.5												
Index (2nd phalanx)		60.0	22.5						2.5					15.0	
Index (1st phalanx)		5.0	72.5	7.5			12.5	2.5							
Thumb (1st phalanx)			32.5	10.0			52.5	2.5	2.5						
Jelly			92.5			5.0	2.5								
Wrist Pad		5.0	85.0	2.5					7.5						
Wrist Band		12.5	62.5											25.0	
Rubber Ball			75.0	25.0											
Large PU Ball				100.0											
Small PU Ball			7.5	92.5											
Hard Earser					95.0	5.0									
Pen	2.5				72.5			5.0	20.0						
Elastic Earser					20.0	80.0									
Small Clock					82.5			17.5							
Wooden Plate								97.5	2.5						
Cosmetics								25.0	75.0						
Spray								42.5	57.5						
Perfume												100.0			
Mobile Phone											52.5	47.5			
Multi-plug										5.0	37.5	57.5			
Earplug			75.0	2.5		10.0	12.5								
Wash Sponge			47.5											5.0	47.5

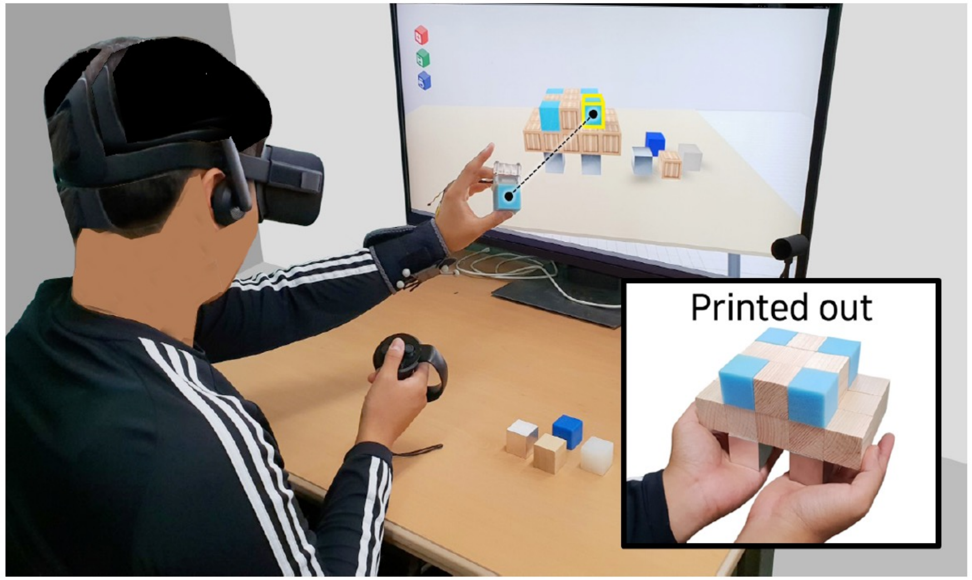
Performance Improvement

- The system can be upgraded by building models for each set of objects to improve recognition accuracy
  - Classifiers are trained on both the materials and shapes of objects
- The recognition accuracy is nearly 100% by adjusting cut off level δ



Applications – VR

- The system helps instill tangibility into block-based modeling
  - 3D modeling with blocks is popular such as Minecraft and isometric toolkits in Unity
- It affords an authoring environment of manipulation, representation and haptic sensations
  - Transforming multi-block models to CAD models
  - Material-rich 3D printing



Applications – AR

- The system can be used for drawing in a 3D space while holding an object in the hand wearing VibEye
- Objects can be anything, but what you draw reflects the texture of objects
- Based on the tangible object, it can transfer the visual and haptic analog experiences to the digital domain
- It helps render different haptic properties such as texture, elasticity, and friction

Conclusion

- VibEye is a system for vibration-mediated object recognition
  - Hardware requires only a vibration emitter and a sensor
  - Software processes the data using well-defined image-based methods
- The approach to the vibration-based object recognition problem is converted to an image classification problem by the spectrogram of objects
- The system was validated with 16 standard objects and 25 everyday objects with 20 participants
  - It was also demonstrated by the two tangible applications for VR and AR

Thank you