Controlling Acoustic Properties using Kinetic Surface

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Abstract
Nowadays, systems like kinetic façade, that actively and efficiently adapt to the ever-changing environment are being applied to buildings. Kinetic surface, which moves and changes surface shape, has a potential as an element that can envelope a space and dynamically control the environment.
As part of the environment, Sound should be considered as a part of the environment and should be controlled in various spaces, not just in concert halls. Therefore, this study aims to plan and analyze kinetic surfaces for sound control. This study conducts a simple ray-tracing simulation in accordance with the state of change in the kinetic surface. Through the distribution of that ray striking the target surface, the pattern of sound distribution in space for each transformation of the kinetic surface can be examined.

Keywords: Kinetic; Acoustic Panel, Ray-tracing

1. Introduction
Human activities take place in both natural and artificially created environments. As an artificially created environment is designed to be controlled, it provides us with a stable living environment where natural forces, including climate and sunlight, do not affect us critically. With a growing level of control, artificially created spaces have evolved to make interior environment pleasant to stay. With the introduction of glass windows, it has become possible to make indoor environment brighter, and owing to the development of air-conditioning systems, it is possible to maintain constant temperature and humidity for us to stay pleasantly.
As part of the environment, sound affects us physiologically, psychologically, and cognitively and it affects our behavior. The sound around us always affects us even though we are not conscious of it (Julian Treasure). Thus, sound should be considered as a part of the environment and should be controlled in various spaces.
Nowadays, kinetic façade systems that actively and efficiently cope with the ever-changing natural environment are being applied to buildings. It provides shades, creates an optimal shading effect to control

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the environment within the building. In addition to providing a shade, kinetic surface, which moves and changes surface shape, has a potential as an element that can dynamically control the environment of environment.

This study aims to analyze the acoustic property by setting a kinetic surface that changes the surface shape. Set up a kinetic surface using 3D modeling tool to measure the distribution and intensity of the reflected sound as the surface state changes. Using the ray-tracing method within a certain time, the behavior of the reflected rays will be visualized. Through this process, the possibility of acoustic property control of kinetic surface will be analyzed.

2. Sound design
Sound travels in air, and when it strikes a surface, it is reflected, absorbed, and transmitted. Of these, reflection is used in ray tracing—a sound analysis method. By analyzing the direction of the reflected sound, the tendency of sound to concentrate or scatter according to the shape of the surface can be predicted. Further, when simulation is carried out with the energy calculation of sound waves, reverberation and sound pressure in space can be explored.

Fig.1. Acoustic Reflection by Geometry

The basic module of a sound kinetic surface was made by a method that transforms through exchange between the Anechoic Surface and Reflective Surface that have contradicting characteristics (anechoic surfaces have the characteristics of an anechoic panel, which is designed to form an angle at which the reflected wave cannot escape from a deep corner. By referring to this geometry, space reverberation is expected to decrease). This modification allows the space in the acoustic state to convert into the anechoic state with the kinetic surface as a sound device in an ordinary state without a sound device. In addition, in the intermediate state, this study aims to predict what kind of acoustic effects can be produced through reflection distribution of sound.

Fig.2. Basic Module and Acoustic Properties

3. Installation and Ray-tracing simulation in applied space
This study conducts a simple ray-tracing simulation in accordance with the state of change in the kinetic surface. It sets to 180° when the component has the shape of a flat reflector. (a) It measures the intersection point at which the ray reaches the target surface by reflection when the surface is set in the state of 180°, 120°, 60°, and 0°, respectively.

Sonic source is placed in the space with 17 × 9.5 × 6 m³ volume, which was set for the experiment. By projecting 196 lines from the sonic source, and visualizing the direction and distance traveled by the sound waves for 150 ms, a trend of acoustic reflection is explored.

Fig.3. Sonic Source and Target Surface Setting
Fig. 4. Module Transformation and Surface Geometry

Table 1. Ray-Trace Result by Different States

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<tr>
<th>Floor plan Diagram</th>
<th>Sectional Diagram</th>
<th>Perspective</th>
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<tr>
<td>a) 180°</td>
<td><img src="image" alt="Diagram" /></td>
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<td>b) 120°</td>
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<td>c) 60°</td>
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<td>d) 0°</td>
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Fig. 5. Distribution of Reflected Ray on Target Surface

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<thead>
<tr>
<th>a) 180°</th>
<th>b) 120°</th>
<th>c) 60°</th>
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The floor at which people listen to the sound by standing is set as the target surface. At this point, the sound that reaches the listener directly from the sonic source is the same in any space with any geometry, and accordingly, the direction of sound source is set in a way that it does not reach the target surface. Through the distribution of that ray striking the target surface, which is the floor, the pattern of sound distribution in space for each transformation of the kinetic surface can be examined.

4. Analysis

When a completely flat kinetic surface of a) 180° is considered as space in which no sound devices are installed, distribution of the acoustic arrival point shows a dense pattern as it is more distant from the sonic source. Compared to this, in case of b) 120°, it shows a more uniform distribution in the direction to which the sound wave is headed. Through this, it is expected to exhibit the most stable and uniform sound effects in the absence of additional sound reinforcements such as a speaker. c) A random distribution appears in case of 60°. Given the ray-trace diagram in the table, the effect of even distribution of the directionality of the sound wave is the greatest. d) 0° has a function that traps the sound as intended by the kinetic component design.

5. Conclusion

The ray-tracing simulation of a kinetic surface that can control the sound with various surface shapes, demonstrated the expected performance in case of d) 0°, which is the intentionally designed to be flat. Furthermore, when the kinetic surface transforms only into several intended states, the expected performance is bound to appear. However, in the case of the kinetic surface explored in this study, the results were irregular for b) and c) with the exception of the intended design of a) and d). Particularly, regarding c), a uniform distribution was expected at a closer distance from the source given the observation and expectation for a) and b). However, actual results were measured as a new performance called dispersion of sound. As a result, it can be inferred that it has a different sound effect in each of the three states, except a). b) exhibited a uniform distribution of sound over the entire surface and c) showed a characteristic of scattering the sound evenly by dispersing the directionality. d) has a performance similar to sound absorption.

Based on these results of the analysis, it could be predicted that the kinetic surface for sound has different acoustic characteristics depending on the condition. However, since only four states were analyzed, there may be missing omissions of other characteristics that were not observed. In addition, there is a limitation that the observation was conducted only for a short time of 150 ms for intuitive analysis.

In conclusion, although the kinetic surface for the sound examined above moves continuously, sound effects do not continuously increase or decrease according to the geometry of the surface; however, the characteristics vary according to the surface state.

References