Researchers Develop Algorithm to 3D Print Vibrational Sounds

OCT 28 2015 | BY HOLLY EVARTS | PHOTO: CHANGXI ZHENG; VIDEO: GAURAV BHARAJ, DAVID I.W. LEVIN, JAMES TOMPKIN, YUN FEI, HANSPETER PFISTER, WOJCIECH MATUSIK, AND CHANGXI ZHENG

In creating what looks to be a simple children's musical instrument—a xylophone with keys in the shape of zoo animals—computer scientists at Columbia Engineering, Harvard, and MIT have demonstrated that sound can be controlled by 3D-printing shapes. They designed an optimization algorithm and used computational methods and digital fabrication to control acoustic properties—both sound and vibration—by altering the shape of 2D and 3D objects. Their work—"Computational Design of Metallophone Contact Sounds"—will be presented at SIGGRAPH Asia on November 4 in Kobe, Japan.

To demonstrate their optimization algorithm, the researchers built a "zoolophone," a metallophone with playful animal shapes.

"Our discovery could lead to a wealth of possibilities that go well beyond musical instruments," says Changxi Zheng, assistant professor of computer science at Columbia Engineering, who led the research team. "Our algorithm could lead to ways to build less noisy computer fans, bridges that don't amplify vibrations under stress, and advance the construction of micro-electro-mechanical resonators whose vibration modes are of great importance."

Zheng, who works in the area of dynamic, physics-based computational sound for immersive environments, wanted to see if he could use computation and digital fabrication to actively control the acoustical property, or vibration, of an object. Simulation of contact sounds has long interested the computer graphics community, as has computational fabrication, and, he explains, "We hoped to bridge these two disciplines and explore how much control one can garner over the vibrational frequency spectra of complex geometrics."

Zheng's team decided to focus on simplifying the slow, complicated, manual process of designing idiophones, musical instruments that produce sounds through vibrations in the instrument itself, not through strings or reeds. Because the surface vibration and resulting sounds depend on the idiophone's shape in a complex way, designing the shapes to obtain desired sound characteristics is not straightforward, and their forms have been limited to well-understood designs such as bars that are tuned by careful drilling of dimples on the underside of the instrument.

3D metallophone cups automatically created by computers

To demonstrate their new technique, the team settled on building a "zoolophone," a metallophone with playful animal shapes (a metallophone is an idiophone made of tuned metal bars that can be struck to make sound, such as a glockenspiel). Their algorithm optimized and 3D-printed the instrument's keys in the shape of colorful lions, turtles, elephants, giraffes, and more, modeling the geometry to achieve the desired pitch and amplitude of each part.

"Our zoolophone's keys are automatically tuned to play notes on a scale with overtones and frequency of a professionally produced xylophone," says Zheng, whose team spent nearly two years on developing new computational methods while borrowing concepts from computer graphics, acoustic modeling, mechanical engineering, and 3D printing. "By automatically optimizing the shape of 2D and 3D objects through deformation and perforation, we were able to produce such professional sounds that our technique will enable even novices to design metallophones with unique sound and appearance."

Though a fun toy, the zoolophone represents fundamental research into understanding the complex relationships between an object's geometry and its material properties, and the vibrations and sounds it produces when struck. While previous algorithms attempted to optimize either amplitude (loudness) or frequency, the zoolophone required optimizing both simultaneously to fully control its acoustic properties. Creating realistic musical sounds required more work to add in overtones, secondary frequencies higher than the main one that contribute to the timbre associated with notes played on a professionally produced instrument.

Looking for the most optimal shape that produces the desired sound when struck proved to be the core computational difficulty: the search space for optimizing both amplitude and frequency is immense. To increase the chances of finding the most optimal shape, Zheng and his colleagues developed a new, fast stochastic optimization method, which they called Latin Complement Sampling (LCS). They input shape and user-specified frequency and amplitude spectra (for instance, users can specify which shapes produce which note) and, from that information, optimized the shape of the objects through deformation and perforation to produce the wanted sounds. LCS outperformed all other alternative optimizations and can be used in a variety of other problems.

"Acoustic design of objects today remains slow and expensive," Zheng notes. "We would like to explore computational design algorithms to improve the process for better controlling an object's acoustic properties, whether to achieve desired sound spectra or to reduce undesired noise. This project underscores our first step toward this exciting direction in helping us design objects in a new way."

Zheng, whose previous work in computer graphics includes synthesizing realistic sounds that are automatically synchronized to simulated motions, has already been contacted by researchers interested in applying his approach to micro-electro-mechanical systems (MEMS), in which vibrations filter RF signals.

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