Research Statement

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Past Research

For the past 10 years, I have been studying computational algorithms to support engineering designs. It is very difficult for non-experts to design functional shapes such as clothing, furniture and musical instruments. Therefore, I proposed to integrate real-time simulation and optimization into the modeling system so the designer can always get feedback from the simulation. We have conducted various studies that can be classified into four categories: (1) interactive shape editing incorporating real-time simulation, (2) modeling complex dynamic phenomena (3) user-controlled simulation, and (4) technology for editing complex shapes.

(1) Interactive design incorporating real-time dynamics simulation

Since the simulation response to the design variable is highly nonlinear and difficult to understand intuitively, it is difficult to improve the design based on the simulation result. Therefore, presenting the results of physics simulations during interactive shape editing allows the designer to easily create functional objects. Specifically, it has become possible to design free-form metallophone by developing a technique that performs eigen-analysis of deformation using the finite element method in real time during shape editing [14, 25]. By combining the eigenvalue analysis of the sound field using the boundary element method with the shape change, it has become possible to design a flute or ocarina with a specific scale [2]. By applying the sensitivity analysis to the finite element method shell analysis including buckling, it became possible to design the pattern of the clothing by leveraging the interactive simulation [13]. In another study, we developed a system that makes it easy to search for original designs by simulating the strength and stability of furniture is made of square wood planks [5,10]. This study not only returns simulation results, it also automatically illustrates several design alternatives for the user, presents a range of physically valid furniture designs during user editing, etc. A new interaction method was also explored.

(2) Modeling complex mechanical phenomena

I studied the modeling of mechanics to achieve better trade-off between speed and accuracy of the simulation. First, we proposed a new structural model based on the beam theory, which instantly detects structural flaws in a three-dimensional design [20,22]. We also worked on the modeling of non-linear dynamic phenomena using machine learning. First, for applications such as games, we built a model that calculates the non-linear formation of wrinkles in clothes from a large amount of precomputed cloth deformation data [7].

We also worked on modeling nonlinear correspondence between aerodynamic results and design using machine learning. A technique for learning the lift/drag characteristics of wings based on the flight trajectories of a large number of paper airplanes was proposed [6]. In addition, we proposed a model for lift/drag characteristics in a given direction for a 3D object based on spherical harmonics to simulate complicated motion of falling objects and design of 3D kites. The presented model acquisition from example videos of falling objects [4]. We also proposed a machine learning model based on Bayesian theory that instantaneously predicts the flow, pressure distribution, and drag coefficient around a 3D shape [1].

(3) Real-time simulation and control of complex physical phenomena

Slender objects such as hair and string exhibit complex deformation with strong nonlinearity through the interaction of bending and twisting, but it has been very difficult to stably simulate such behavior in real-time. In our research, we proposed a method to stably simulate the complex movement of rod-like objects in real-time based on Cosserat theory [21]. In addition, we proposed a technique that enables simulation in real-time using the position-based dynamics method for a technique for controlling the state of deformation by giving an example of the deformation [24].

(4) Technology for editing complex shapes

A system [3] for designing an electrical circuit on a three-dimensional shape was proposed. Also, a deep learning method was proposed in which the design space is modeled by parametrizing the three-dimensional shape with a subdivision surface [17].

Future Research Plan

I have been studying engineering design through cross-disciplinary approaches combining mechanical engineering and computer science. Usually, I determine the research topic with an open mind, discussing the real-world problem with engineers to narrow down a simple and concise problem statement in the research. While I will maintain such a flexible attitude, I consider the following three broad research themes.

(1) Physical phenomena modeling using machine learning

I have used machine learning to model non-linear correspondence between design variables and simulation results for nonlinear mechanical phenomena such as clothes deformation [7] and aerodynamics [1,4,6]. Research has been conducted to optimize the design. I would like to further develop this approach so it can be adapted to more complex phenomena. For example, we are considering machine learning of the correspondence between the body shape and fluid noise and predicting the stress applied to the blood flow and blood vessel surface from the blood vessel shape instantaneously using machine learning in cerebral aneurysms. Many plastic products are made using injection molding, but designing the mold requires the knowledge and experience of a skilled engineer, making it difficult to automate the design. We want to make it easy to design the mold by determining the correlation between the shape of the mold and the resulting defects in the injection molding results using machine learning.

Also, knitting is difficult to simulate because large amounts of yarn are brought into contact and interact with each other to deform with high nonlinearity. I would also like to take on the challenge of modeling such aggregate interactions using machine learning. If it can be applied, we believe knitting patterns can be optimized to be more comfortable.

(2) 3D shape recognition for interactive shape editing

Deep learning has made great progress in auditory and visual media, but progress is still slow for three-dimensional shapes. I proposed mesh-based machine learning of 3D shapes and a method for learning 3D shapes and learning simulation results linked to 3D shapes [1,17]. I would also like to work on machine learning of 3D shapes for applications that support interactive shape editing. For example, a system is considered in which when a two-dimensional sketch is an input, a three-dimensional shape is output. Such technology will greatly reduce the time from concept design to product design. Another possible application is to anticipate the user's intention in the middle of shape modeling and edit ahead.

(3) Support for intelligent design

I believe the ultimate goal of design support research using machine learning is to create a design system with the same level of cognitive ability as humans. The current design system still requires humans to determine the shape, covering all the various constraints such as functionality, aesthetics, cost, and manufacturability. These constraints are very difficult for a computer to handle because the evaluation function is often ambiguous or difficult to express with mathematical formulas. My goal is to model such subjective values using the machine learning through large amounts of data to achieve more intuitive mechanical designs.