公開

研 究 終 了 報 告 書

「フード 3D プリンターと人工知能を使用して食事体験を向上させる計算フードテクスチャ」

研究期間: 2020 年 11 月～2023 年 3 月
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1. 研究のねらい

Food texture is a sensory experience that integrated multisensory stimuli to influence the taste of food. It affects how eating experience gain during the meal. However, such experience usually obscures by the food allergic and oral issues. This project aims to physically augment foods that users want to eat but it does not have the opportunity to eat due to the fact of food allergic or any physical health condition. To do so, I proposed the technique that generate the food texture of the target allergic food on the different type of food using artificial intelligence and printed with a food 3D printer. For example, produce carrot with steak textures of steak with chicken texture based on the estimation of the biological information from the users as the dataset to generate the texture parameters from the target food to the user (Figure 1). This research explores a new direction that integrate 1) AI to analyze and determine the food texture, and 2) the enhancement of food 3D printer to produce several foods.

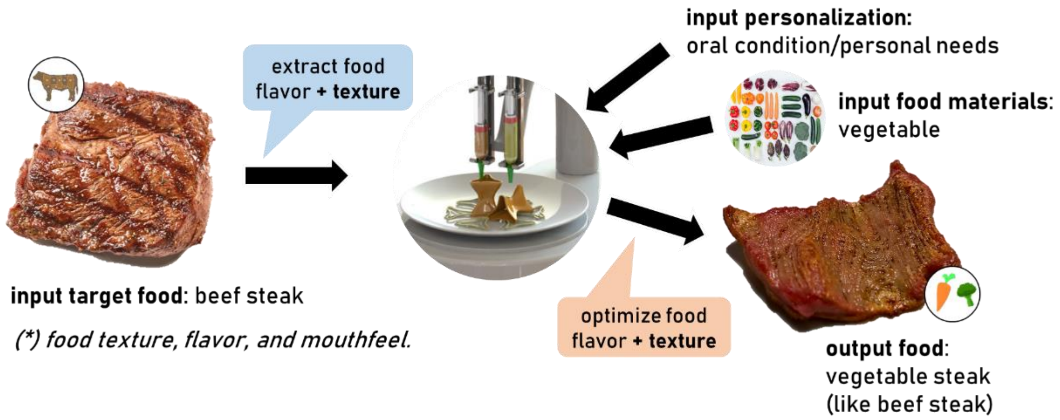

Figure 1 This research project aim to generate the food texture on an alternative food to allows users with food allergic to experience the food with different textures.

2. 研究成果

(1)概要

In this research project, I have conducted three research themes that corresponding to achieve the first step in fabricate alternative food through food texture with food 3D printer. First, I have investigated the relationship between food texture with chewing pattern, setup the systems for data collection, and collect the food texture dataset to fabricate the food with different food textures. Second, I have explored the computational framework that would allows to generate the food internal structure based on the force that applied to the food. Finally, I have investigated the computational interaction technique that estimate the chewing sound based on the internal structures. These results provided a guideline for future investigation in food fabrication with food 3D printers.

（2）詳細

In the period of 2.5 years, I have conducted three research themes, which corresponding to achieve the first step in fabricate alternative food through food texture using food 3D printer, as follows.

Research Theme A [Development of Data Collection Systems for Food Textures]

To understand the relationship between food texture, taste, and food materials as the input for generate the alternative food with various food texture, it is important to collect the food textures data based on the various type of food materials and examine several types of food textures. This research aims to develop a data collection system for collecting the food textures data. To do so, this research develop a experimental framework that took the chewing pattern from the users when consume the food with different internal structures (e.g., Hilbert, Rectilinear, and Octet infills), and questionnaire that questions regards the mouthfeel when consume those food textures (Figure 2). The data is used as the training data to predict the target food perception based on

Figure 2 Data Collection in which the participants are asked to record EMG and take questionnaires.

the food textures parameters. Finally, this research collects the separated data from the actual foods for the calibration with the food that create from food 3D printer. The end-to-end process for data collection systems to generate the food textures shown in Figure 3. The systems consist of the target-based model (predictor/training), and end-to-end model (interference).

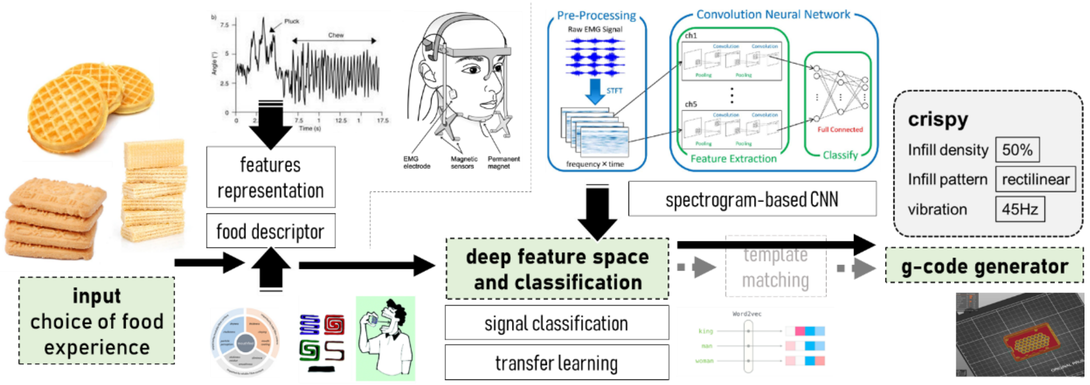

Figure 3 End-to-End workflow for data collection and generate food texture with food 3D printer.

End-to-End model: the end-to-end framework is built upon the target-based model by considering the actual food structures to calibrate its food textures to match the food texture generated with food 3D printer. This process utilizes the gradient-based method to estimate the number of features (jaw movement and time series) that closely matched to the food texture from the target-based model, and then estimate the prospect 3D printed food with optimized food textures.

Research Theme B [Computational Framework for Generate Food Internal Structures]

On the promise to enable the different food texture, one possible direction is to modify the food structure based on the force that apply to the foods. This research proposed the neural synthesizing topology optimization to address a coordinate-based network for implicit neural represented structural topology optimization for computing fine and smooth structure with competitive performance, and a self-supervised auto-decoder network for further generating a series of structures under continuous boundary conditions. The network consists of two combination coordinate-based network (oscillator network) and shape representation (modulator network). The framework is shows in Figure 4. In short, the physical solver adopts finite element analysis (FEA) to compute the structure performance, and the oscillator network represents the structure in an implicit neural form for super-resolution, and a modulator network enhances the network expressiveness for multi-structure generation. First, the oscillator network inputs an n x 3 coordinates array X to generate an initial structure P. Second, the physical loss function L of the structure P is computed from the FEA solver. Third, the gradient of less L is backpropagated as BP(L) to update the oscillator network. After the iterations of the above steps, the user may infer a super-resolved structure by inputting the coordinates array of an s-times denser grid.

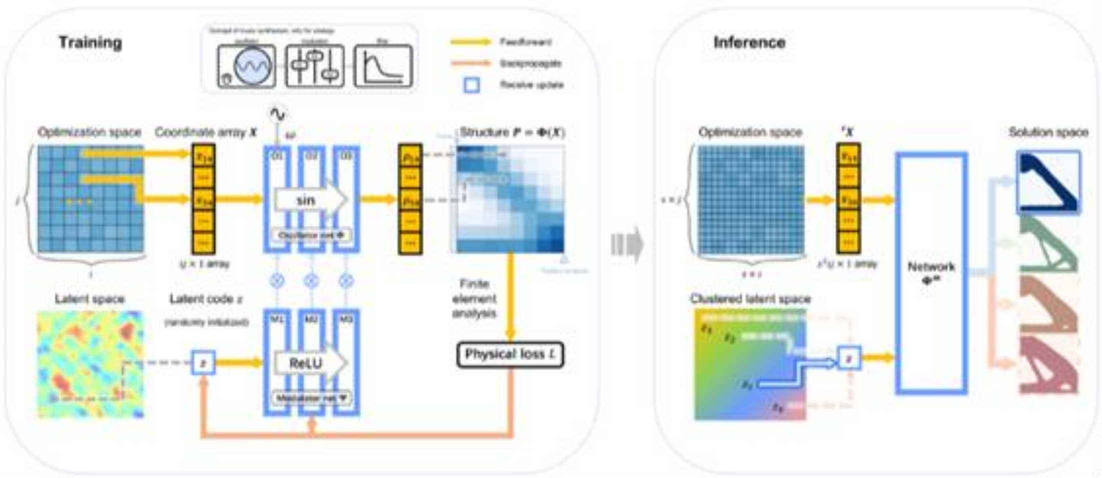

Figure 4 For single structure optimization, the oscillator network imports coordinate array X from optimization space and exports structure P, finite element analysis is performed to get the loss L. For solution space generation, the modulator network activates. Multiple subtasks are simultaneously optimized, and their corresponding latent codes z are randomly initialized, input, and optimized with network parameters.

<u>Performance:</u> the performance of this method is based on two aspects; (1) the convergence and structural performance compared to those of the benchmark method, and (2) the computation time for tasks with complex structures and boundary conditions. As also shown in Figure 5, the performance of the structures were comprehensively compared. The proposed method has lower compliance than SIMP in all the benchmark cases. The clear structure boundaries of the proposed solutions are also led to minor efforts in mesh postprocessing (before actual fabrication). To demonstrate the use case, the dual networks has been leveraged to generate the shell optimization under a varying volume constraint. The thin shells were optimized under different radial tension, and axial pressure. The diameter height ration was set as the dynamic boundary condition to find the optimal design scheme for the different materials.

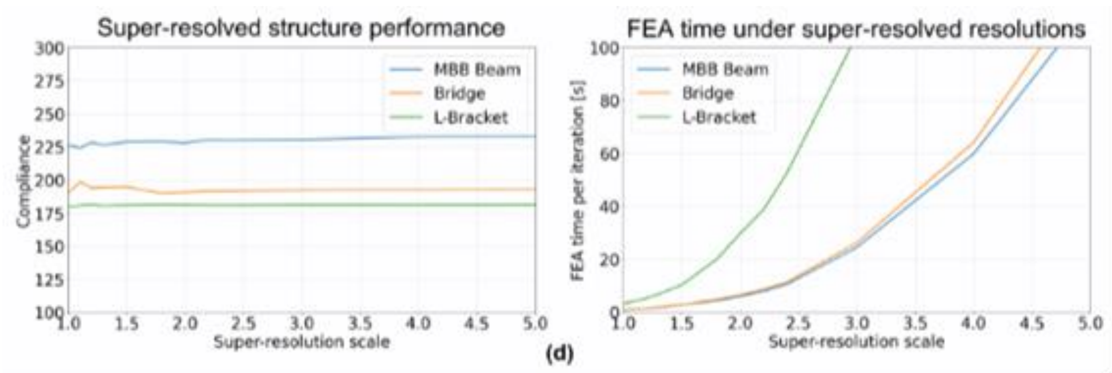

Figure 5 Performance of several super-resolved results and the orinary FEA iteration time under same resolution.

Research Theme C [Computational Interaction for Sound Prediction for Food]

The material elastic property is the basis of numerical simulation and optimization of structural vibro-acoustic performance. In the solid behavior, its can be indicated by the structural composition modal vibration and impact sounds. Similar to the edible space, such impact sound can be identified as the biting and chewing behavior. The chewing sounds that reflected from the food could be used to estimate the texture of the food. Therefore, this research theme proposed a modal-impact-sound-based estimation method for 3D printing material through its elastic property. To simplify the problem, this research based on the level of elastic materials either edible or non-edible. For edible, it should be noted that the modal is transfer from the non-edible materials. The modal impact sound refers to the mechanical waves that radiate from a structure vibrating surface excited by the impact force (in the edible case, with the biting behavior), and it is well established in the field of acoustics. Using this modal impact sound, this research proposed a numerical-experimental estimation method, which estimates the material elastic property by minimizing the residuals between simulated and recorded modal impact sound features.

Experimental and Results: the experiment is conducted through the recoded of impact sounds using 16-bit depth. The specimens are printed with either FDM 3D printer (for non-edible) and food 3D printer (for edible). If mode 1 of specimens x, y, and z are used for estimation at the same time, Young's modulus E_1, E_2, and E_3 will have a similar sensitivity scale. In conclusion, the numerically demonstrated the superiority of this method is compared with SOAR in acoustic material elastic property estimation. The result shows that the proposed method is capable of instant convergence while having low estimation residuals.

3. 今後の展開

From the results of this research project, there are the remaining step to achieve the research goal such that the utilize the data and the systems to generate different food texture on the various types of food materials. Specifically, I would like to expand the results of this research project on the two specific research area: (1) on the HCI, and (2) computational fabrication.

On the HCI aspect: it is important that the end-user could be allowed to use the system freely without request the professional setting. Therefore, the next development would be to integrate the tools for end-to-end fabrication pipeline that would allows the user to use the systems to generate the food texture without requiring superior experiences.

Computational Fabrication aspect: allowing fabricate the food texture with various type of food, it is required the computational model that could represents different type of food textures, and with different types of fabrication parameters. In my future development, I will utilize the computational systems to fabricate and measure the food textures to collect various food data that allows to build the computational aspect of the food textures. Specifically, in the research theme A, this area of development has been started, but yet in the broad variation of the food materials. Therefore, it would be interested to further investigate on the area of computational fabrication to extend the limited of the food materials.

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4.　自己評価

Based on the research objectives, research progress, and the impact of this research project on science and technology, I believe that this research project would advantage to the various research societies both on the computer science and engineering. Although the current research achievement is not yet reaching the research goal, I believe that the results are promising on the ground on the preparation stage to achieve the prospect research goals.

Future prospects: in this regard to the future prospect, this research achievement could allow to establish a new research aspect on Human-Food Interaction or Computational Food Interaction by interdisciplinary integrating the knowledge from both computer science (ground on HCI, and material science) and engineering (i.e., material engineering, etc.).

5.　主な研究成果リスト

（1）代表的な論文（原著論文）発表

研究期間累積件数：6件 （3本リストアップ）

1. Yamamoto Miyatake, Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. interiqr: Unobtrusive Edible Tags using Food 3D Printing. In Proceedings of the ACM Symposium on User Interface Software and Technology (UIST) 2022, pp. 84:1-84:11. Bend, USA, October 2022
This paper presents a method that utilizes the infill parameter in the 3D printing process to embedded information inside the food that is difficult to recognize with the human eye. The key technique is to utilize the air space or multi-material to generate a specific pattern inside the food without changing the model geometry.
2. Shengze Zhong, Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. NSTO: Neural Synthesizing Topology Optimization for Modulated Structure Generation. Computer Graphics Forum (Special Issue Pacific Graphics 2022), Volume 41, Number 7, September 2022.
This paper proposed the neural synthesizing topology optimization that leverages a self-supervised coordinate-based network to optimize structures with significantly sorter computation time, where the network encodes the structural material layout as an implicit function of coordinates.
3. Motoki Miyoshi, Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. SoftPrint: Investigating Haptic Softness Perception of 3D Printed Soft Object in FDM 3D Printers. Journal of Imaging Science and Technology (Proceedings of Printing for Fabrication 2021), Vol. 65, No. 4, pp. 40406:1-40406:8(8). July 2021.
This paper offers a means of providing the desired softness perception of a printed surface and the desired roughness to expand the haptic dimension over which a user can exert control. Specifically, this study allows to control the softness of 3D printed objects by manipulating the infill structures of a printed surface.

（2）特許出願

研究期間全出願件数：0 件（特許公開前のものも含む）

（3）その他の成果（主要な学会発表、受賞、著作物、プレスリリース等）

受賞

1. Outstanding Paper Award, IEEE Life Sciences and Technologies (LifeTech) 2021.

プレスリリース等

1. 食べられるデータの埋め込みを実現フード3Dプリンターで食品内部に2次元コードなど～食品のDXのための新技術～，令和4年10月17日，科学技術振興機構（JST）/大阪大学, https://www.jst.go.jp/pr/announce/20221017/index.html
2. 「食べられる情報」がもたらす新たな食体験とコミュニケーション．令和4年12月17日，Promotion Trend Media, https://bae.dentsu-pmp.co.jp/articles/foodtech-3dp