Computational Personalization through Physical and Aesthetic Featured Digital Fabrication

Ryota KAWAMURA

Graduate School of Library, Information and Media Studies

University of Tsukuba

03 2019

Contents

List of Figures

Chapter 1

Introduction

1.1 Background

Development have been changed as digital fabrication technologies spread. As the result, we realize personal fabrication, that enables all users to develop without any specific instruments which conventional craftmen needed. The next society we should aim is so diverse that realizes personalization, the optimized development for each person.
Personalization needs to input user's own data as the design parameters into the system which generates 3D models, however these methods cost. In this thesis, we seek computational personalization to design conventional stabilizers seen in photography and videography based on user's physical data, and the assistive device for visually impaired people based on user's aesthetic data.

1.2 Organization of the Thesis

First, we review the related research areas in digital fabrication and personalization in Chapter 2, and clarify the position of our overall attempt and each contribution. We also clarify terminologies used in this thesis.
In chapter 3, we describe the physical-based design method that ergonomically personalize 3D printable stabilizer in detail. The contributions presented in this chapter has been published as Exo-Balancer: Design Method of Personalized Stabilizers for Shooting Actions [17] in *Proceedings of the 9th Annual ACM Symposium on Augmented Human International Conference* (AH ′18) in Seoul, Korea, and we update this method which is going to be published as Design Method of 3D Printable Ergonomically Personalized Stabilizer at *the 21st HCI International 2019* (HCII ′19), Florida, USA.
This work was conducted in collaboration with Kazuki Takazawa, Riku Iwasaki, Kenta Yamamoto, and Yoichi Ochiai from the University of Tsukuba.
In chapter 4, we describe the aesthetic-based design method that personalize the assistive device for visually impaired people in detail and validate its effectiveness through a user study with both students familiar with 3D modeling and not. This work was conducted in collaboration with Keisuke Shimakage, Kengo Tanaka, Yoichi Ochiai from the University of Tsukuba, and Yoshihiro Asano from Keio University.
Finally, we discuss the limitations and future works in chapter 5, and then summarize our contributions in chapter 6.

Chapter 2

Related Work

2.1 Physical Featured Personalization

2.1.1 Commercial Strategies for Supporting Photography

Currently, camera photography and videography can be observed in some situations such as when people capture a photograph of everyday life or when a professional photographer shoots a film. To support photography and videography, camera shake correction techniques are now available on many cameras, which benefits users. Camera shake corrections are divided into two methods: a *software-based* approach that realizes correction with electronic calculations such as electronic image stabilizing, and a *hardware-based* approach that realizes the correction with optical image stabilization. Thus, each image stabilizing method installed on camera presents its own advantages. However, disadvantages also occur for these methods, in that users cannot receive any photography support unless they own the camera because different cameras involve different image stabilizing techniques. Old and cheap cameras most likely do not possess any of these techniques; hence, the quality of photography and videography would depend on a user's skills.

Electronic image stabilization techniques installed on camera can be defined as a *software-based* approach, and numerous investigations based on software have been conducted [37, 39, 19].

Meanwhile, optical image stabilization techniques installed on camera can be defined as a *hardware-based* approach, and numerous investigations based on hardware have been conducted [8, 29].

Commercial stabilizers have been developed to avoid such a hardware dependency, as shown in Figure 2.1. A stabilizer is a photographic instrument directly installed on the body of a photographer. It enables a smooth operation even with a large camera. Many commercial stabilizers can reduce camera shake from handheld devices to devices attached to users. Although a handheld stabilizer is light, it lacks stability. Therefore, professional photographers tend to use a heavy stabilizer. Because they must operate it for a long time, it leads to user fatigue. Thus, the weight of a stabilizer has been related to user fatigue. Currently, brushless gimbals have been used to reduce camera shake and user burden. A steadicam is a conventional device to support camera users and is slightly heavier, whereas brushless gimbals are lighter than a steadicam because their gimbals are controlled computationally. Thus, this device depends on the proficiency of the user, and subsequently the scope of use

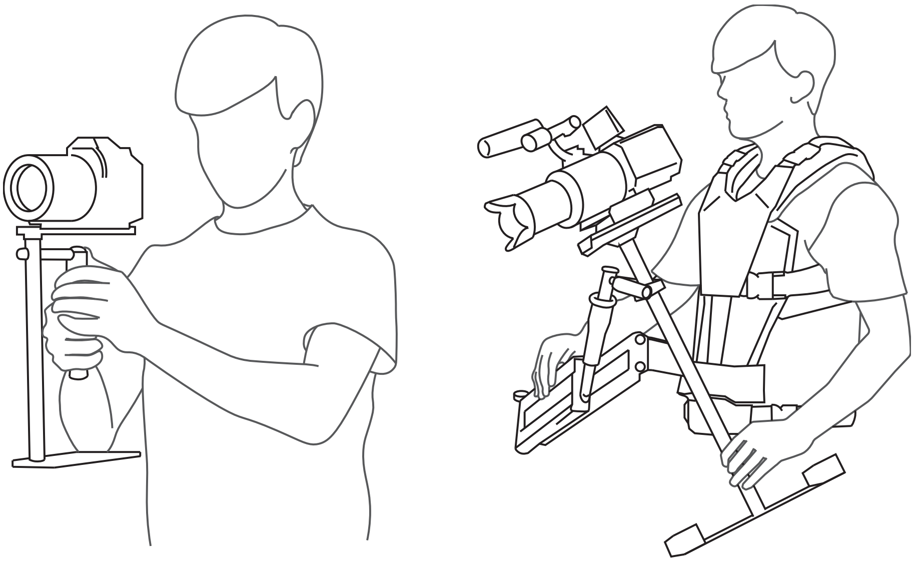

Figure 2.1: Examples of 2-type camera stabilizers. Left: a hand-held device. Right: a device attached to the user to fix a camera for a long time in situations like a film shooting.

is limited to professional photographers. To our knowledge, no method exists that specializes in designing stabilizers for amateur individuals, and they are only shared as 3D models created by volunteers in the design repository.

2.1.2 Optimization with Digital Fabrication

The spread and development of computers have diversified computational design methods. Further, the affinity between digital fabrication and optimization is high, thereby resulting in the development of some products. Koyama et al. presented a computational design method to automatically optimize and create a 3D-printable connector between two different objects [21]. In their study, they provided a simple user interface to users so that they would not be confused. They were only required to adjust the fix-position of two objects and the length between them, and they could choose the suitable design from presented candidate designs. We also adopted the concept to allow end-users to design a personalized stabilizer easily.
Fabrication researchers are also interested in the internal mechanism of 3D objects. Several studies have been conducted widely on balancing 3D objects under certain circumstances such as underwater [45, 33], in air [44], etc. Changing the internal mechanisms of 3D objects also enabled them to stand on a plane [34, 45].
Keeping the balance is useful in real world. Our approach in chapter 3 investigates the moment of forces to keep balances between the user and instruments consisted of some kinds of connected equipments such as a camera, monopod, 2 bungee codes, and 3D-printed components to be placed between a monopod and harness.

2.1.3 Topology Optimization

Shape optimization is important in computational design. In particular, topology optimization is a typical shape-optimization method. Several professional software are available to

support the generative design in the market such as ANSYS [1] and the components in the framework of Grasshopper plugin [2]. Topology optimization, in which inefficient materials are removed iteratively from a structure while efficient materials are added to the structure simultaneously, obtains the best layout of materials within a limited design space, and maximizes the system performance. Optimized structures sometimes exhibit limitations regarding shape, thereby rendering them difficult to reproduce on an industrial scale. However, a breakthrough in reproduction was achieved from digital fabrication [1].
The design method to optimize shape by topology optimization has often been investigated in human-computer interaction. For instance, Chen et al. [6] presented a user-driven generative design method using topology optimization. Kazi et al. [18] also used topology optimization and function for a sketch-based generative design. We also used topology optimization in the method describe herein this paper, which is on the Grasshopper as an add-on. When using the add-on and realizing topology optimization on Grasshopper, some components functions are used as the inputs of topology optimization. Thus, our method of conducting topology optimization is conventional from the viewpoint of direct inputs.

2.2 Aesthetic Featured Personalization

The comprehensive research area of assistive technologies are not only in usual daily scenes where non-handicapped people live, but also in serious daily scenes where handicapped-people face. Therefore, some functional and aesthetic design method for assistive devices have been presented. Following the background, in this section we clarify the position of OtonGlass in assistive technologies in category 1: assistive technologies for visually impaired people, and describe its goal in category 2: aesthetic design for these assistive devices.

2.2.1 Assistive Technologies for Visually Impaired People

The purposes of assistive technologies for visually impaired people can be classified into three categories: navigation, vision correlation, reading support.
Many researches for navigation with wearable devices such as Head-Mounted Display (HMD) Eye Glasses for augmented reality (AR) have also been conducted [52, 4, 52, 50, 3, 41], and these attempts are sometimes seen in welfare field [32]. Also a research using wearable device for organs other than eyes has been reported [12].
As for visual correction, there are many studies applying these wearable devices. Based on the case of optical see-through HMD, its vision enhancements address the problem of amblyopia or color vision deficiency [22, 42, 31, 51, 38, 23] and simulate some kind of visual impairments for people with general eyesights [2]. Meanwhile, eye glasses have been used to enhance the reading skill of patients with macular degeneration as their rehabilitation [27].
As for reading support, to remove the constraints that conventional products for visually impaired people and explore alternative to directly reading action by recognizing texts visually, for example Kane et al. installed a camera onto a desktop to recognize user action and then identifies and reads texts ideally for the position [13]. As the typical study using wearable devices, some researches exist to externalize the input part for reading from eyes

[1] https://www.ansys.com/products/structures/topology-optimization
[2] http://www.grasshopper3D.com/forum/topics/stress-topology-optimization-with-millipede,https://www.food4rhino.com/app/ameba-rhino

to fingers by attaching the small device including a camera to the finger [40] or attach the device to a hat or sunglass [48]. However, there have any studies using wearable devices like Eye Glasses or HMD in this field. Therefore, we must explore the possibility whether these devices adjust this field or not.
Glasses-type devices for assistive technology has also been developed and produced not only in academic but also industry fields. *OrCam*, glass-type device for visually impaired people developed by the startup in Israeli, allows the wearer to read the texts on the signboard when he or she points at it [3]. These functions are diverse and it also enables to read texts on books automatically or voice guidance when traffic signals change. However, we have been driving projects while the environment of their development environment is closed. As the result, we aim to realize the goal that develop personalized device for each person by positively disclosing information about our development to users.

2.2.2 Aesthetically Designed Products

It is one of the noticeable contexts that assistive devices has been becoming wearable as the development of computer resources provide thin, small, and light electronic devices. In this category, we describe the aesthetically designed products.

Collaboration with Professional Designers

To combine aesthetics with product, collaboration with professional designers is one of the most fundamental method. Creative design process by collaboration between designers and computer sciences has generated innovative products. Deepwear enabled collaborative and creative design process between human and machine intelligence design process in which images that deep convolutional generative adversarial networks (DCGANs) generate are used for pattern maker to create clothes [16]. Ellustrate enabled to design functional and aesthetic electronic circuits with conductive and non-conductive materials [26]. As the design exploration of conventional crafts, LÃĺvy and Yamada fabricated and evaluated 3D-modelled and 3D-printed utensils for the Japanese tea ceremony [25]. Interestingly enough in that paper, they described that mechanical limitations such as printers or materials sometimes created uncontrolled yet beautiful irregularities. Wang et al. held the workshop collaborated with professional designers and explored the conceptual design space. Thus, user-driven design process inspire users and enable to design more creative works.

Collaboration with end-users

While professional designers often involve in these methods because of their sophisticated design skills as mentioned in the previous category, it was difficult for end-users to do that because they generally lack these skills. Emergences of a 3D printer and a laser cutter contribute to the opportunity that provides personal fabrication to all users. 3D CAD software is useful to engineers who are familiar with digital fabrications, meanwhile end-users generally cannot use them easily because their mechanism is complicated. Therefore, end-users are restricted to use design repositories like Thingiverse[4], which are rich in 3D object files and propose the opportunity where end-users download them freely. However, end-users

[3] https://www.orcam.com/en/
[4] https://www.thingiverse.com

cannot revise them according to their use after downloading. To address the problem, there are a number of researches about design methods that propose the intuitive user interface to end-users. As the pioneering study of computer-assisted parameter settings, Marks et al. present the novel interface called Design Galleries, which is generally applicable to several parameter setting tasks [28].

Also, we need to extract their own aesthetics that they have inside for design from them. As the approach using user's visual aesthetic preference, Koyama et al. expanded [43] and realized self-reinforcing color enhancement system that learns user's preference [20]. In their paper, they argued that automatic personalization have some limitations: non-correspondence to different preferences and then professional photographers actually do not accept it because of its scenario-dependent design.

Chapter 3

Physical Design Method of 3D Printable Ergonomically Personalized Stabilizer

In this chapter, we firstly introduce the Exo-Balancer, our first design method for a personalized stabilizer, and the evaluations. Next, we enumerate some issues to be addressed. Subsequently, we describe the implementation by computational optimization in detail.

3.1 Introduction

In photography and videography, it is a challenge to align sight towards the target continuously and steadily, which often requires a lot of practice and experience. Blurry photos are often taken by camera users who lack the necessary skills. To address the problem, stabilizers have been developed. Conventional stabilizers have a steep learning curve because they are designed to be mass-produced, and thus not tailored according to the individual. For example in filming location, large equipments or manpower have been used to move a photographer smoothly, mainly because conventional stabilizers have less customizability for various uses. And to begin with, stabilizers for professional users are so heavy in general that a photographer cannot do on any actions other than photographing. The spread of image sharing application leads to an increase of the number of camera users; nevertheless, this is where things are currently in photography and videography. Non-personalized stabilizers bring out the result to lack of user experiences. For example, some users suffer from holding a camera with their hands for a while. To achieve the goal that all users can operate stabilizers comfortably and enjoy photographing without any stresses, we need to build the design framework of personalized stabilizers without any costs such as transport or human power, produced by the simplified manufacturing line which has the possibility of customization.

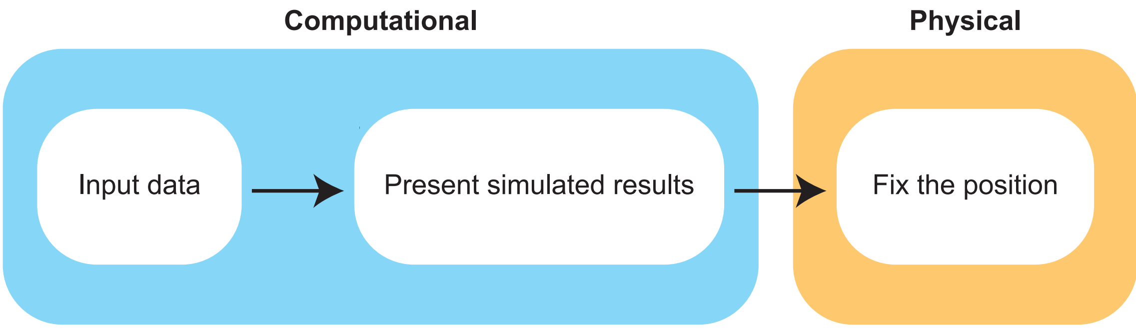

Figure 3.1: Overview of our system. The blue area represents the computational phase, and the yellow area represents the physical phase.

3.2 First Approach

3.2.1 Implementation

As the first step to realize our goal, we had made the following attempt: Exo-Balancer. Its simple overview is shown in Figure 3.1.

Calculation Using Body Data

Our goal is to personalize a stabilizer such that users can capture photographs without any stress. Hence, we focus on the moments of forces. We present a design method to obtain a suitable position for each user from a balance relation between forces and moments according to their body data and the fixed angles of an object. First, users input the length from their shoulder to lumbus (its value is n, see Figure 3.3) as their basic body data, the angle θ_b that sets the upward-facing horizontal as positive, and fixes a camera. According to the horizontal and vertical equilibrium of forces, the following equations are obtained:

$$F = m_f g \cos\theta_b + F' \cos\theta_a + m_c g \cos\theta_b \tag{3.1}$$

$$F' \sin\theta_a = m_c g \sin\theta_b + m_c g \sin\theta_b \tag{3.2}$$

where F is the force on the point-on-contact between a harness and monopod, while F' is that on the point-of-contact around the shoulder of the user. L is the length from a harness to a camera, while x is the length from a harness to the point that supports a monopod; l is the length from point to A. We ask the user to hold a camera in advance, and measure the distance from the camera position to where the harness is to be attached (its value is L, see Figure 3.3). We apply L to the measured value. As shown in Figure 3.3, θ_a is the angle between the line segment from B to C and the line segment from A to a camera. The moment of forces around C is as follows:

$$\frac{x - L}{2} m_f g \sin\theta_b = (L - x) m_c g \sin\theta_b \tag{3.3}$$

From equation (1) to (3), we gain equations about x as follows:

$$x = \frac{(2m_c + m_f)L}{2(m_c + m_f)} \tag{3.4}$$

Figure 3.2: our instrument assembling some parts consisted of ready-made goods and components printed with a 3D printer

We define the equation $F = F'$ as the requirement that minimizes the forces on the user body and calculate them on Unity[1]. Subsequently, we solve the following equation:

$$2l^3 + nl^2 - 2l(n^2 + x^2) - n(x^2 - n^2) = 0 \tag{3.5}$$

Our system optimizes the two equations above by inputting x and l, which are based on specific user values. Thus, we obtain the optimally fixed position of a camera for the users.

Assemble Some Parts Using Calculated Results

Next, the users externalize the data to the physical world. First, we attach the harness, which is typically used to set an instrument such as a camera, to the body. A harness comprises a mounting plate; thus, we set a monopod to the mount (see Figure 3.5, right). We printed out the models on a 3D printer (*Makerbot Replicator*)[2] using regular polylactic acid filaments. We set its infill rate to 100% because it must withstand some forces and support some parts. Figure 3.2 shows the result after assembly, and its process is shown in Figure 3.4.

3.2.2 Evaluation

In this section, we describe the experimental evaluation of our approach. Our evaluation involved a qualitative evaluation to interview the participants in our experiment about

[1] https://unity3D.com
[2] https://www.makerbot.com/3D-printers/replicator/

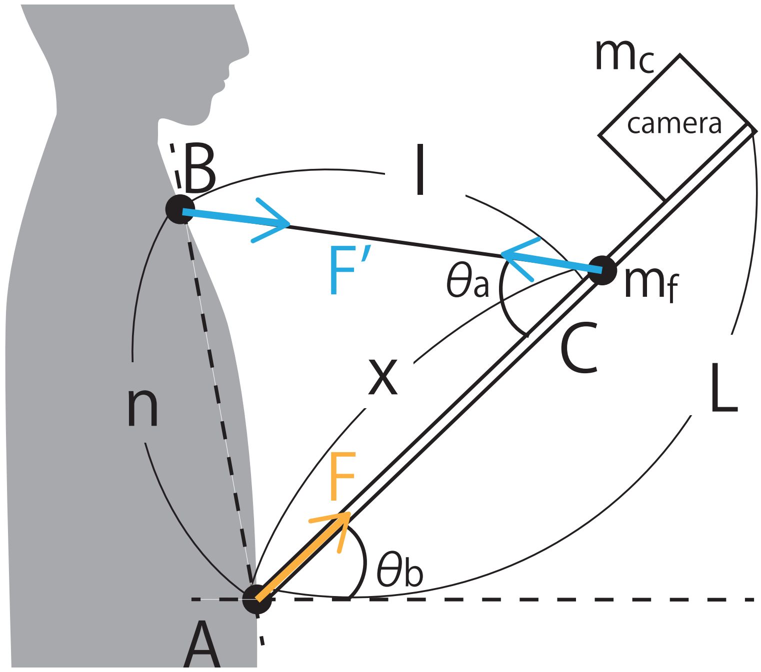

Figure 3.3: Simple configuration image of our instrument. This image includes the applied forces, the masses of a few instruments, and the angles when the user is equipped with our instrument.

Figure 3.4: Left: all of parts we prepared. They consists of a monopod, harness, bungee code, and 3D-printed components. Center: assembly phase of these parts. Right: the user is equipped with our instrument.

the practicability of our instrument and a quantitative evaluation based on a three-axis acceleration sensor to measure the shakiness of a camera. First, we asked the participants to capture videos for 30 s to verify the effect of our personalization. The participants conducted this phase four times: hold a camera with their hands, hold a camera with our method, hold a camera with our method while changing x slightly from the calculated results. Thus, we investigated whether our design method had resulted in personalization. Next, we conducted an interview and some questionnaires. In addition to the quantitative evaluation, we compared the impact on a camera with that on our instrument as a qualitative evaluation. We measured the values on a three-axis acceleration sensor attached to a camera and compared them.

Participants

To verify the practicability of our method, we recruited college students (1 female, 7 males) as participants. They had different physique. They were aged between 18 and 25 years (M

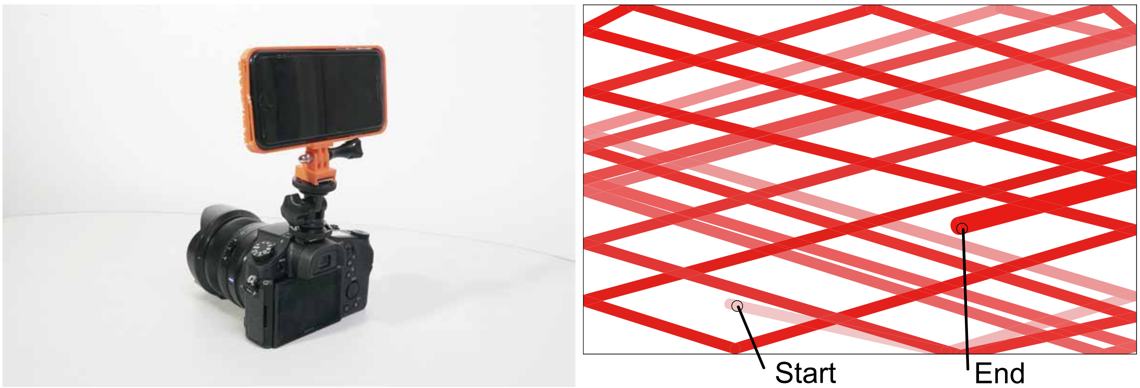

Figure 3.5: This is the setup of our experiment. Left: the camera used in our experiment. We attached iPhone 6 in order to measure the gravitational acceleration from its acceleration sensor inside it. Right: a scene of our experiment. We projected a video in which a red ball was bouncing onto the wall. Right: The locus of the red ball in our experiment.

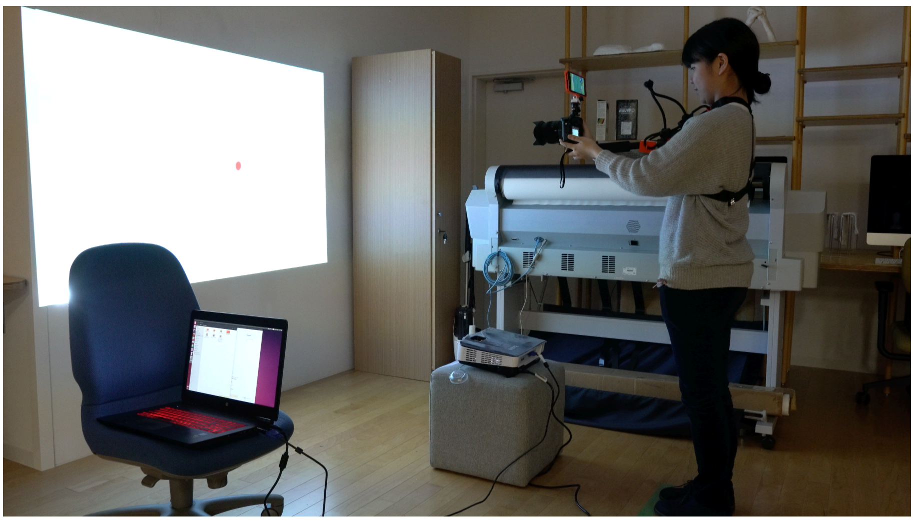

Figure 3.6: This is actual experimental scene.

= 20.4, SD = 2.0) and were not familiar with the stabilizer of a camera.

Experimental Procedure

To calculate the parameters for personalization, we first equipped the participant with a harness and adjusted the length to fit to their bodies. We measured two lengths: one is between the shoulder and the mount of a harness (n, as mentioned in the section, "Simulation using body data"), and the other is between the mount of a camera and the mount of a harness (L, as mentioned in the section, "Simulation using body data"). To define L, we asked the participants to hold a smartphone when they capture a photograph. We input these values for the participants' own data and calculated x and l. Finally, we assembled the parts and equipped them on the body of the participants based on these values. We projected a video in which a red ball was bouncing onto the wall for 30 s. In our experiment, the participants continued with shooting such that he/she could observe the ball in the middle of the angle of view (see Figure 3.6). It is noteworthy that the ball speed changes randomly when it bounces off the wall (see Figure 3.5 right).

Usability in Personalizing Shootings

As a quantitative evaluation, we interviewed the participants. The purpose of this interview was to reveal how the users felt when using our instrument. To investigate the usability and enjoyability, we asked them to rate each question in a five-point Likert scale, from "strongly disagree" to "strongly agree." In addition, we asked for details with free-description questions. We used the two-tailed Wilcoxon signed-rank test, which is non-parametric method and evaluated at an alpha level of 0.05. Scores of each question were analyzed on a five-point Likert scale. We also analyzed two cases derived from our method similarly when we changed the value of x deliberately to verify the propriety of our method (see Figure 3.7, Q1-Q4). In addition to these questions, to investigate the usability, we prepared two questions regarding the enjoyability (see Figure 3.7, Q5, Q6). Finally, we asked the participants for details with free-description questions.

3.2.3 Results

Figure 3.7 shows the results from all six questions. These questions aim to reveal the usability (Q1-Q4) and enjoyability (Q5, Q6).

The first question pertained to the operability when the participants captured a photograph. In the conventional style, they are required to hold a camera at all times with both hands while bending a little and look into the finder. However, our method is different, in that we only need them to hold a camera with one hand and operate the other instruments with another hand while grasping a monopod. The Wilcoxon signed-rank test demonstrated no statistical significance between methods A and H ($Z = -0.79$, $p > 0.05$), A and B ($Z = 0.00$, $p > 0.05$), and A and C ($Z = -0.63$, $p > 0.05$).

The second question pertained to the stability when the participants captured a photograph. We focused on whether the participants felt stable to explore the usability. The Wilcoxon signed-rank test demonstrated no statistical significance between methods A and H ($Z = -1.89$, $p = 0.06$), A and B ($Z = -1.19$, $p > 0.05$), and A and C ($Z = 0.00$, $p > 0.05$).

The third question pertained to the fatigue when the participants captured a photograph.

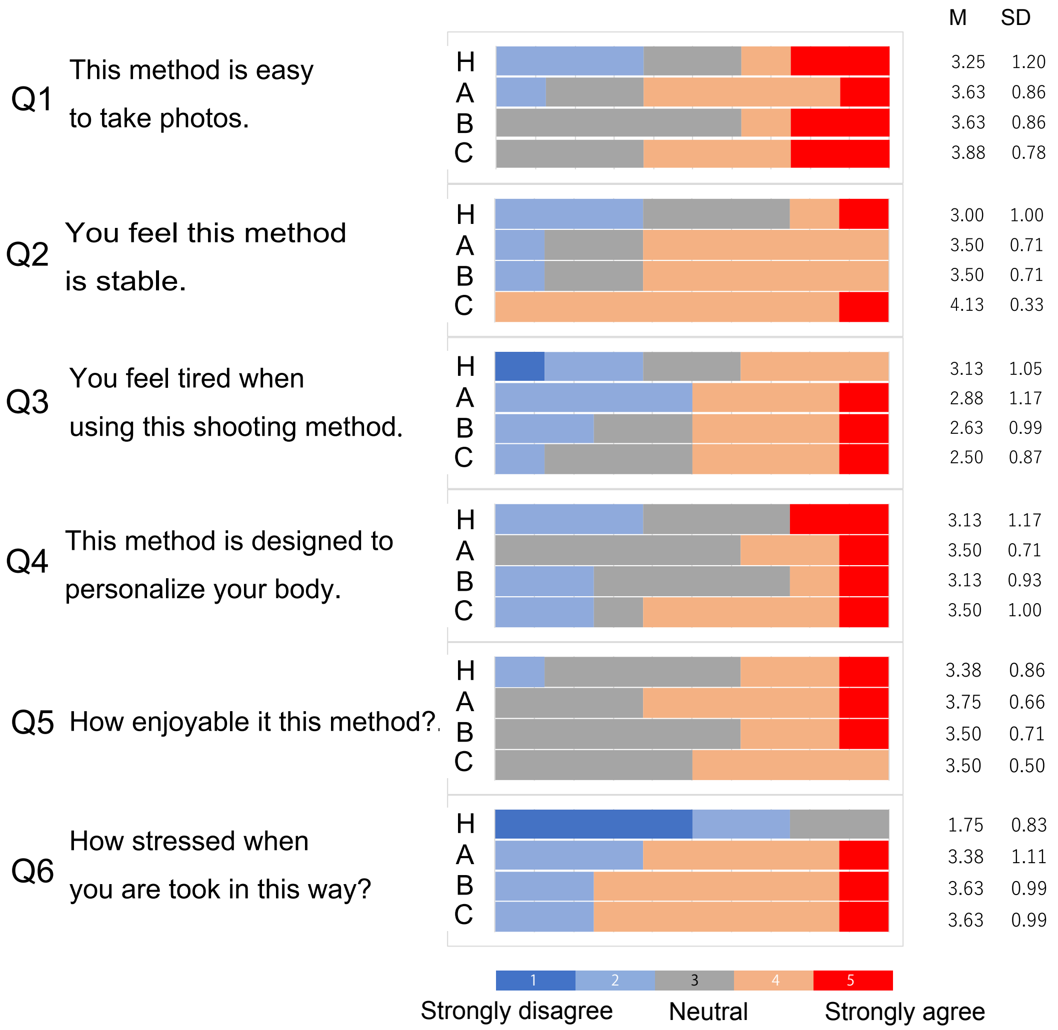

Figure 3.7: Rating the usability of personalizing shootings compared to another 3 methods. Our instrument is used in method A. In method B, x is set to plus 5cm. On the other hand, it is set to minus 5cm in method C. Each question is scored on a 5-point Likert scales.

Fatigue is an important element while investigating the usability. Operability and stability are considered to reduce significantly when fatigue increases. The Wilcoxon signed-rank test indicated no statistical significance between methods A and H ($Z = -0.42$, $p > 0.05$), A and B ($Z = -0.54$, $p > 0.05$), and A and C ($Z = -0.83$, $p > 0.05$).
The fourth question pertained to the personalization of participants. The definition of personalization is obscure; thus, we asked them to determine whether these methods were designed for personalizing their bodies. The Wilcoxon signed-rank test demonstrated no statistical significance between methods A and H ($Z = -1.00$, $p > 0.05$), A and B ($Z = -1.13$, $p > 0.05$), and A and C ($Z = 0.00$, $p > 0.05$).
Unlike Q1, Q2, Q3, and Q4, we set two questions to understand the participants' enjoyability. We verified the enjoyability from different viewpoints.
The fifth question pertained to the viewpoint of the photographer. For instance, some people are motivated to capture a photograph to satisfy their desire in using an exclusive camera, while others are motivated by the opportunity to communicate with friends through an image-sharing application. Thus, we must investigate the positive effect of our method in sustaining people motivation in photography. The Wilcoxon signed-rank test demonstrated no statistical significance between methods A and H ($Z = -1.34$, $p > 0.05$), A and B ($Z = -1.41$, $p > 0.05$), and A and C ($Z = -1.00$, $p > 0.05$).
Meanwhile, the sixth question was based on the viewpoint of the participant. People tend to be daunted when surrounded by large photographic equipment. Meanwhile, they are often relaxed when captured with a smartphone. Thus, we must confirm that our method does not cause mental stress. The Wilcoxon signed-rank test demonstrated no statistical significance between methods A and B ($Z = -1.00$, $p > 0.05$), and A and C ($Z = -1.00$, $p > 0.05$). Meanwhile, a statistical significance exists between methods A and H ($Z = -2.41$, $p > 0.05$). Overall, all the results are attributed to insufficient power.
In addition, according to the participants' personal opinions from the free descriptions, a few participants felt stressed when they captured a photograph using our method. The majority opinions are provided below. P (participant) 7: "*I felt slightly nervous to be targeted by devices that I have not seen.*" *In method B, a participant struggled at capturing an upper photograph.* P8: "*When I tried to capture an upper photograph, I felt inconvenienced because I had to bend my body backwards.*" In method C, a few participants felt a slight tightness when equipped with the instrument. P2: "*It was difficult to capture pictures on the bottom because my body was pulled up.*" P4: "*I felt a monopod sticking in my chest and it was slightly painful when I was equipped with the instrument.*" P6: "*The mounted position of the camera is slightly far from me when using methods A to C; therefore, I felt the weight. However, it was relatively easy to operate the instrument because its distance was the shortest in these methods.*" P7: "*I felt tightness and discomfort around my chest.*"

Analysis of Each Shaky Phenomenon

In addition to a quantitative evaluation using the Likert scale, we conducted a qualitative evaluation that analyzes the values of acceleration sensors that were built into an iPhone. The application we used for this user study was AccelerationLogger[3]. We attached iPhone6 to the top of a camera (see Figure 3.5 left). The data of the participant are shown in Figure

[3]https://itunes.apple.com/jp/app/id340777156

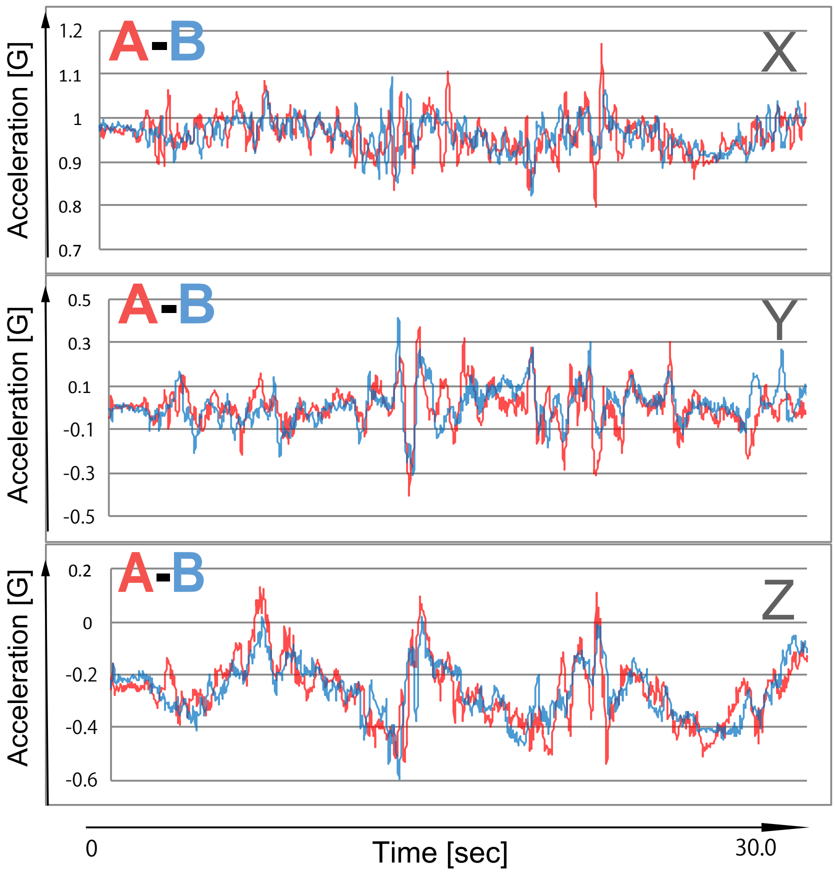

Figure 3.8: Results from captured 3-axis position of a camera. Note that graphs of x-axis, y-axis, and z-axis are shown separately in order to compare each method. Besides, red line represents method A and blue line do method B, which is a pseudo method of method A. And then black frames represent the areas that surround the characteristic range of difference between these methods.

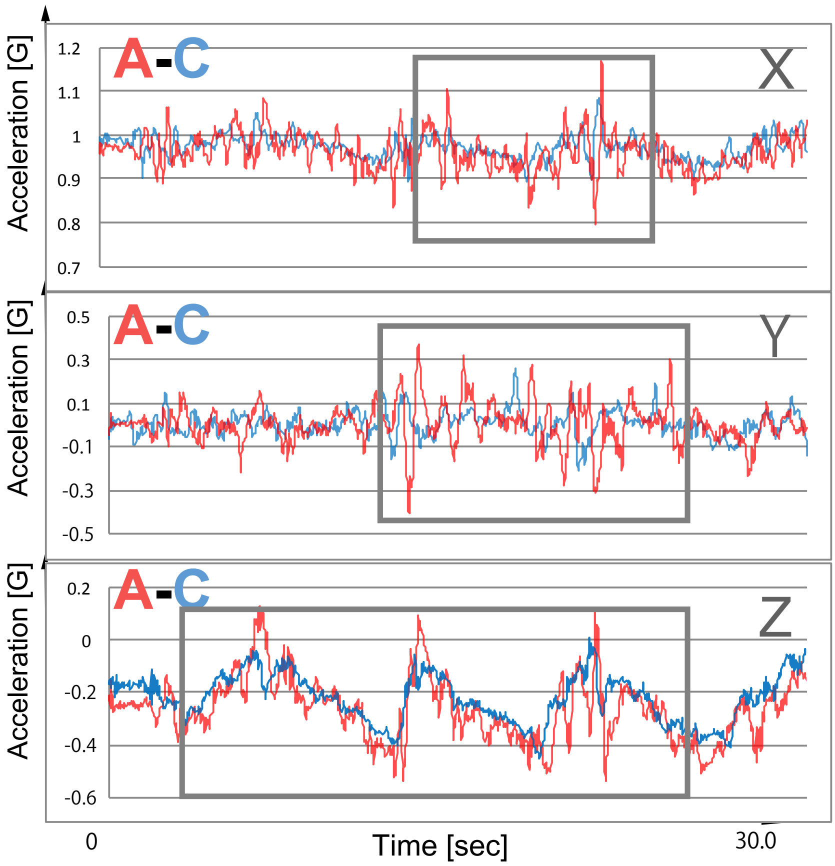

Figure 3.9: Results from captured 3-axis position of a camera. Note that graphs of x-axis, y-axis, and z-axis are shown separately in order to compare each method. Besides, red line represents method A and blue line do method C, which is a pseudo method of method C. And then black frames represent the areas that surround the characteristic range of difference between these methods.

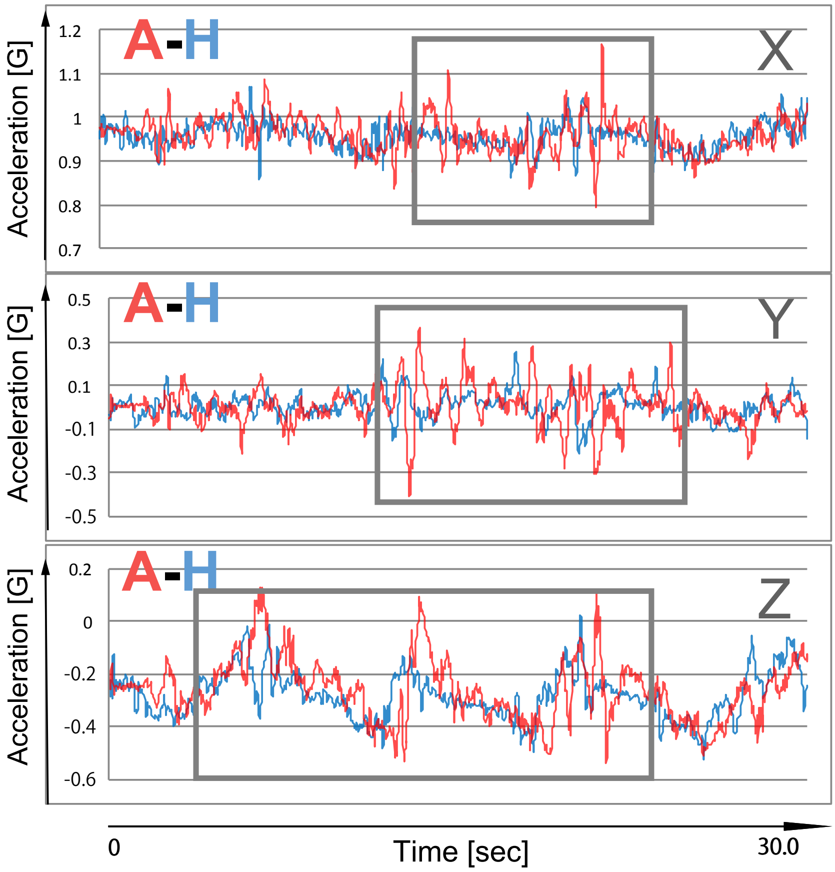

Figure 3.10: Results from captured 3-axis position of a camera. Note that graphs of x-axis, y-axis, and z-axis are shown separately in order to compare each method. Besides, red line represents method A and blue line do method H, which requires only hands of users to hold the camera. And then black frames represent the areas that surround the characteristic range of difference between these methods.

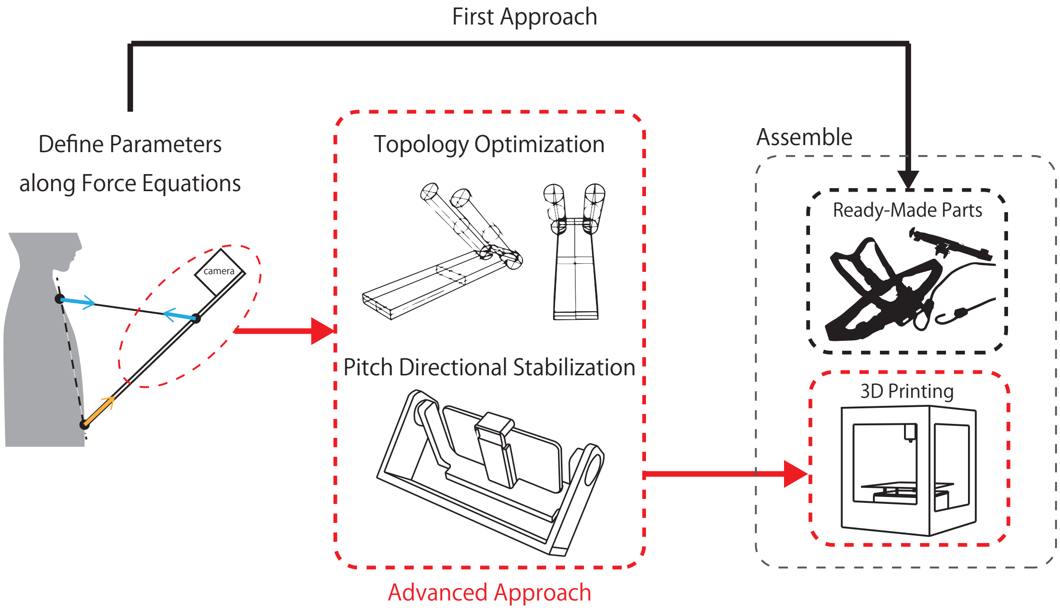

Figure 3.11: System overview. Compared to first approach, advanced approach we described in this section uses shape-optimization method and stabilization structure for pitch directional. It is embodied by 3D printing technologies without assembling some ready-made goods.

3.8, 3.9, and 3.10 in which the difference in values among the methods was remarkable. In comparison with methods A and H or A and B, a slightly difference was observed. However, we found an interesting difference in comparison with methods A and C. The shake from method C was reduced on all axes rather than that from method A. As described in the next section, method C contributed to the improvement in operability while imposing a burden on the user by reducing x.

Summary

Exo-Balancer is the rudimentary design method for a personalized stabilizer. Based on their physical data, it calculates and presents one of the best fix-positions for users to operate comfortably without any stress. In exploring the position, we considered the moments of forces between the users and equipment such as a harness, monopod, and camera, two bungee cords, and some connectors generated by 3D printers. Subsequently, we recruited participants of different physiques and obtained some results from the quantitative evaluation based on three-axis acceleration sensors on the camera, as well as a qualitative evaluation based on the statistical analysis of the questionnaire.

1. **Low durability because of the property of ready-made goods** A harness is a typical photography-assisting tool; however, the part that is attached to the body stretches when loads are added because it is made of rubber. Therefore, a camera mounted on a stabilizer generates a large torque, resulting in low usability.

2. **Low adaptability for physically characterized people** Ready-made goods are not necessarily customable especially when their specifications are limited. In our method, for example, it is impossible to adjust an equipment (e.g., monopod length) slightly

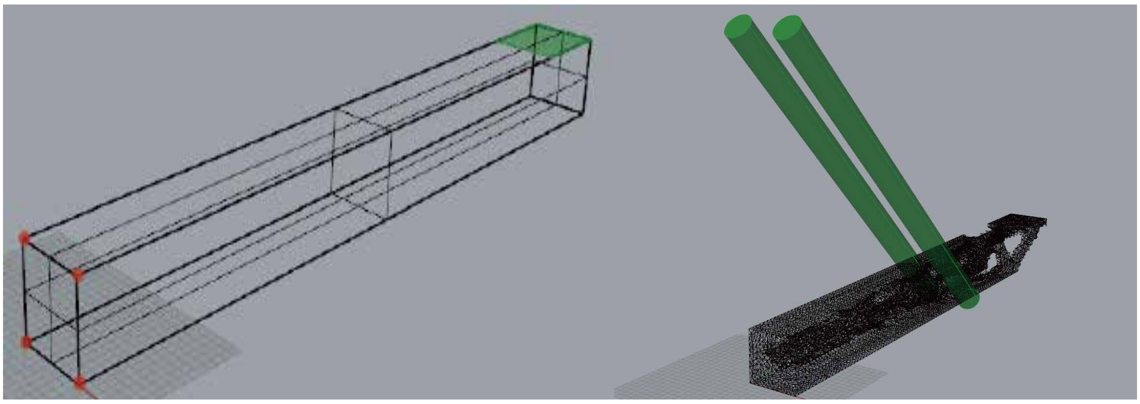

Figure 3.12: System on grasshopper. Left: The supporting points is a red dot, and the green surface is loaded to the Z-axis negative direction. Right: The result model and two supporting poles.

when our participants are extremely fat or small.

3. **Low stabilizing ability** To our knowledge, Exo-Balancer was the first to explore the design space to combine digital fabrication with personalization in producing a stabilizer. Therefore, we first focused on building the whole structure without applying loads compared to conventional commercial stabilizers. Thus, we provided the users an opportunity to experience it as a simple prototype, and expected a specific stabilization mechanism to be the next step.

3.3 New Approach

Hence, it is necessary to conduct shape-optimization based on a user's physical features for personalized stabilizers, and form it through digital fabrication technologies. The system formulates the problem internally as topology optimization, and subsequently forms it using 3D printing technologies using different materials.
We adopted topology optimization, the typical shape-optimization method, as our new approach to address *issue1* and *issue2* described above. We aim to realize a high optimization and end-to-end output by shifting the size optimization of ready-made goods into computational shape-optimization while maintaining the mechanical constraints proposed previously (see Figure 3.11). Regarding *issue3*, we described the structure that enabled pitch directional stabilization when using a compact camera.

3.3.1 Topology Optimization

First of all, *structural domains* mean the smooth area occupied by structures Ω. In topology optimization, we introduce fixed structural domains D and expand the shape-optimization problem from Ω to D. Therefore, topology optimization can be generally formulated as follows:

$$\underset{\Omega}{inf}\ F = \int_D f\left(x,u\right)\chi\left(x\right)d\Omega \tag{3.6}$$

Camera mass	Stabilizer mass	n	L
400g	480g	48cm	43cm

Figure 3.13: Left: Fundamental parameters. Right: we input these parameters into the Python component. Exo-Balancer algorithm is implemented in that component.

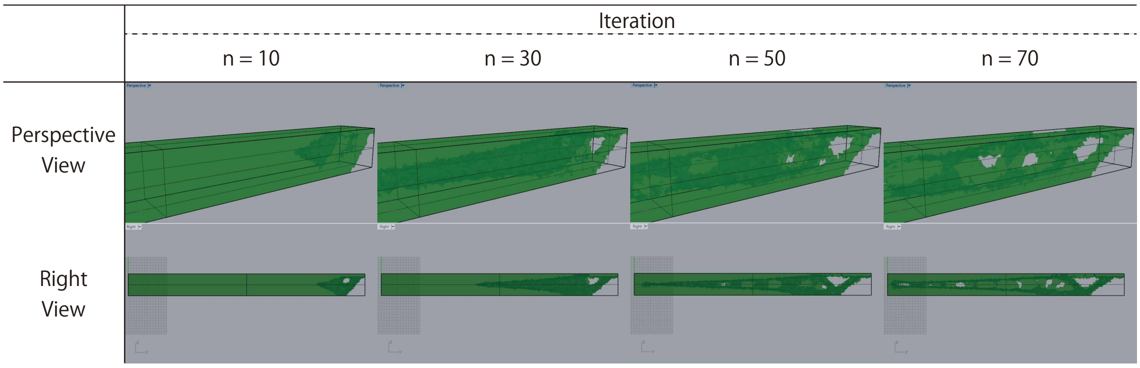

Figure 3.14: Results through each iteration.

where χ represents a characteristic function which value is 1 if the area is in D, and 0 if not as follows:

$$\chi(x) = \begin{cases} 1 & if\ \forall x \in \Omega \\ 0 & if\ \forall x \in D \backslash \Omega \end{cases} \tag{3.7}$$

where χ represents a characteristic function which value is 1 if the area is in D, and 0 if not.

We designed a personalized stabilizer on Grasshopper using add-on *ameba*, developed for 3D topology optimization. *Ameba* is based on the bi-directional evolutionary structural optimization (BESO) technology. Bi-directional evolutionary structural optimization [35, 49] is a finite-element method based on topology optimization, and is significantly more efficient than evolutionary structural optimization [46] in terms of material removal. First, we defined the basic shape of a stabilizer prior to optimization, and both the points to support and the surface on which the load was placed as shown in Figure 3.12 left. It is noteworthy that we allowed the users to hold the steering with both hands in this case to improve operability although Exo-Balancer used both shoulders as a fulcrum (see Figure 3.12 right). Figure 3.13 right shows the Python component of the Exo-Balancer algorithm. The input values to the component consist of camera mass (c_mass), weight of the overall instrument (m_mass), length of user fuselage (bLength_n), and length between their abdomen and the position (mLength_L). According to the algorithm, calculation was conducted for the component. Subsequently, outputs from the component was used for the size optimization of a fundamental stabilizer. Finally, we conducted topology optimization for the shape optimization of a stabilizer. It is noteworthy that loads corresponding to a camera was

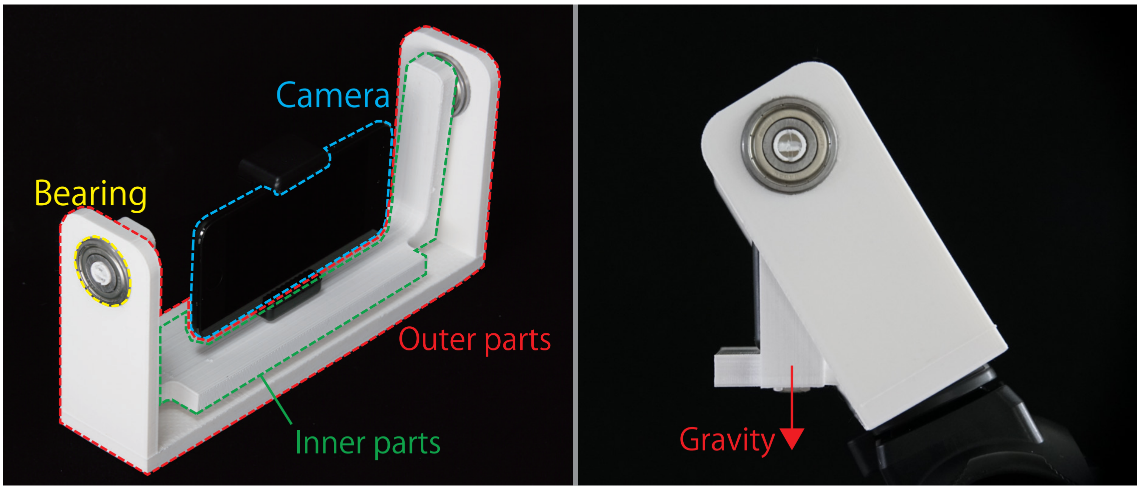

Figure 3.15: Concept image of the structure which realize the pitch directional stabilization for compact camera. These parts unite into one by using a commercial bearing.

applied to the Z-axis negative direction as shown in Figure 3.12 right, the green surface. All parameters including the load for optimization are shown in Figure 3.13 left.
The result is shown in Figure 3.12 right. It can be exported as STL or OBJ file for 3D-printing. The shape transition for each iteration is shown in Figure 3.14.

3.3.2 Pitch Directional Stabilization for Compact Camera

In this paragraph, we describe the structure that enables pitch directional stabilization as the first approach to address *issue3*. When a photographer moves in a certain direction, maintaining the equilibrium according to the direction by his/her own weight stabilizes the pitch direction. Some patents to explore and develop the method have been pended and granted. In particular, we focus on the patent pended by Da-Jiang Innovations Science and Technology Co., Ltd. (DJI)[4]. They filed many patents and invented a connecting device and a gimbal apparatus [30]. Following their idea, we attempted to generate a 3D-printable camera mount on which the structure for stabilization was installed. We designed it on Fusion360, a notable 3D computer-aided design software. Figure 3.15 shows the output through MakerBot Replicator. Our proposed model was divided into two, and we used a commercial bearing to connect with these parts.

[4]https://www.dji.com

Chapter 4

Aesthetic Design Method of Assistive Device for People with Visual Impairments

In this chapter, we describe the user study for computational personalization through aesthetic featured digital fabrication. In chapter 3, we focused on personalizing a stabilizer, which is seen in photography and videography. Meanwhile, we attempt to explore the hackability of assistive technology by using OtonGlass as out research platform.

4.1 Introduction

Assistive technology have high affinity with personalization mainly because its users are physically handicapped. However, almost all assistive devices on the markets have not been designed to enhance the fashionability. Their primary goals are definitely to enhance the usability. On the other hand, industry around physically non-handicapped people have enabled users to choose the best one which they think, and product customization have also recently been accelerated. However, its movement in assistive technology has been deeply slow. As the result, these users sometimes compromise or give up using these devices. Therefore, we functionalize OtonGlass, the glasses-type assistive device for visual impaired people, as computationally personalized device with user's aesthetics, and we held the workshop to verify how users feel it and results in expanding the market of assistive technology.

4.2 OtonGlass

Accessibility to character information has a big influence on productivity and QoL of visually impaired people. Some assistive technologies that support visually impaired reading are used in their lives [General items such as loupe, magnifying reading device, smartphone application], and there are several researches about assistive technologies that supports visually impaired reading in the field of human-computer interaction [Ring, projection]. Nevertheless, they have few options for assistive technologies because more than half of them are too elderly to adjust digital divides. To address the problem, Shimakage et al.

Figure 4.1: A woman wears OtonGlass.

developed OtonGlass for visually impaired people.

OtonGlass, which is a glasses-type assistive device for visual impaired people, has been developed and produced by Oton.inc,. Figure 4.2 (a) shows the system of OtonGlass, which is divided into the cabinet and glass: the former consist of Raspberry Pi, lithium cell, and stereo minijack, and the latter has camera module and shutter button. captures text with the camera at the forehead position, performs Optical Character Recognition (OCR) and Text to Speech (TTS) on the cloud through the Internet, and generates sound of texts (shown in 4.2 (b)). A user can understand its contents by listening to the sound through earphones or speakers. Eyeglass type enables intuitive operation, so even visually impaired people who are not tolerant of new technology can use it like Figure 4.1. As the next step to spread OtonGlass, we focus on the design driven by user's visual authentic preference.

4.3 Implementation

As shown in Figure 4.3 (a), its internal structure has no potential to explore the design space conventionally. Therefore, a user must accept the design when wearing OtonGlass. To acquire user more and maximize the likelihood of future market expansion, we need to redesign it based on its aestheticity.

To verify that users can accept these devices if they are designed with their visual aesthetically, we attempted to redesign OtonGlass through aesthetic featured digital fabrication. Our method is so fundamental: 1) make the cabinet design more user-friendly and 2) add some design parameters to them. While the GUI based design method lowers the threshold level of the end user, it has a disadvantage that it can not design in detail. As the alternative method for these novices, introduction of programming that regard the web as the design platform has been recently in the spotlight. Although there was a programmable method as

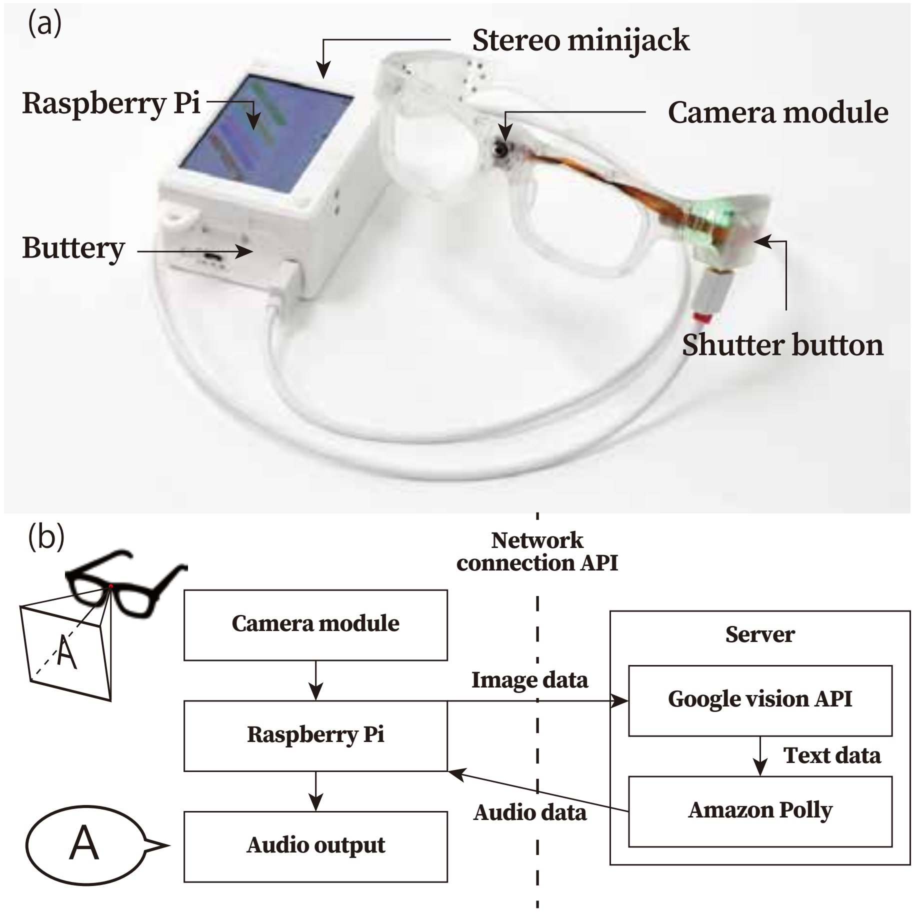

Figure 4.2: (a)OtonGlass consist of a Raspberry Pi, a camera module and a speaker. The enclosure assembled by outputting parts with 3D printer. (b)The captured image is sent to the server constructed, converted to text using OCR, and audio data is generated using TTS. The generated sound data is downloaded to the processing unit, and the user understands the contents by inserting earphones or speakers on the main body side and outputting sounds.

typified by OpenSCAD [3], 3D modeling in combination with simple web programming such as HTML and CSS is not only a very useful technique for many users who are not familiar with hardware computing, but also able to let users who do not have coding skills adjust some parameters and realize their favorite 3D model by sharing created 3D models by all over the users on original design repository [14, 47]. Some existing design repositories like Thingiverse proposed 3D models and ask users to modify these models on 3D CAD softwares, and its task is so hard for users who are not familiar with these technical softwares, Thingiverse has been developing services specialized in sharing customizable 3D models within the service, however it is indescribable that its service is for novices of 3D-modeling because it is based on OpenSCAD. Compared to these conventional strategies, in particular CraftML [47] is a comprehensive design platform that also functions as a design repository. All CraftML user have to do is to learn minimum knowledge of web programming languages such as HTML and CSS.
However, it is not a design method like CraftML that made it possible to make detailed end-to-end designs, but the general and conventional approaches based on graphical user

[3]http://www.openscad.org

Figure 4.3: (a) The cabinet of OtonGlass printed by 3D-printer of Fused Deposition Modeling (FDM). (b) and (c) mean 3D-printed samples in Figure 4.4. (b) Frog was 3D-printed by Makerbot Replicator and (c) chameleon was 3D-printed by formlabs Form2 [2]https://formlabs.com

interfaces (GUI) for end users on Fusion 360 because the targets in this thesis is non-novices of 3D-modeling.

We firstly tried to attach an existing 3D-model from commercial design repogitories to the OtonGlass. In order to construct the 3D model desired by the user, we searched for an existing design repository on the web, screened out the 3D model which we would like to base on the design of OtonGlass, and then designed it on Autodesk Fusion 360. Note that, it is preferable that user's aesthetic preference is reflected in the detailed structure of the model. Therefore, we adopted a simple design process that allows the user to edit the details structure on Fusion 360 and finally realizes a desired model by performing boolean operation between two models. Figure 4.4 represents the original 3D-model and the one of the cabinet of OtonGlass, which we actually created along these processes. These models were presented to the participants to assist their creation in the workshops described below. Figure 4.3 (b)(c) represents the actual fabricated ones by some 3D-printers.

4.4 User Study

The effectiveness of our concept was investigated in terms of both evaluating design process (creativity or simplicity), and comparing user-driven OtonGlass and the conventional one. In this section, we show the results from two user studies, i.e., the usability of the system, and the comparison of OtonGlass whether based on their will or not.

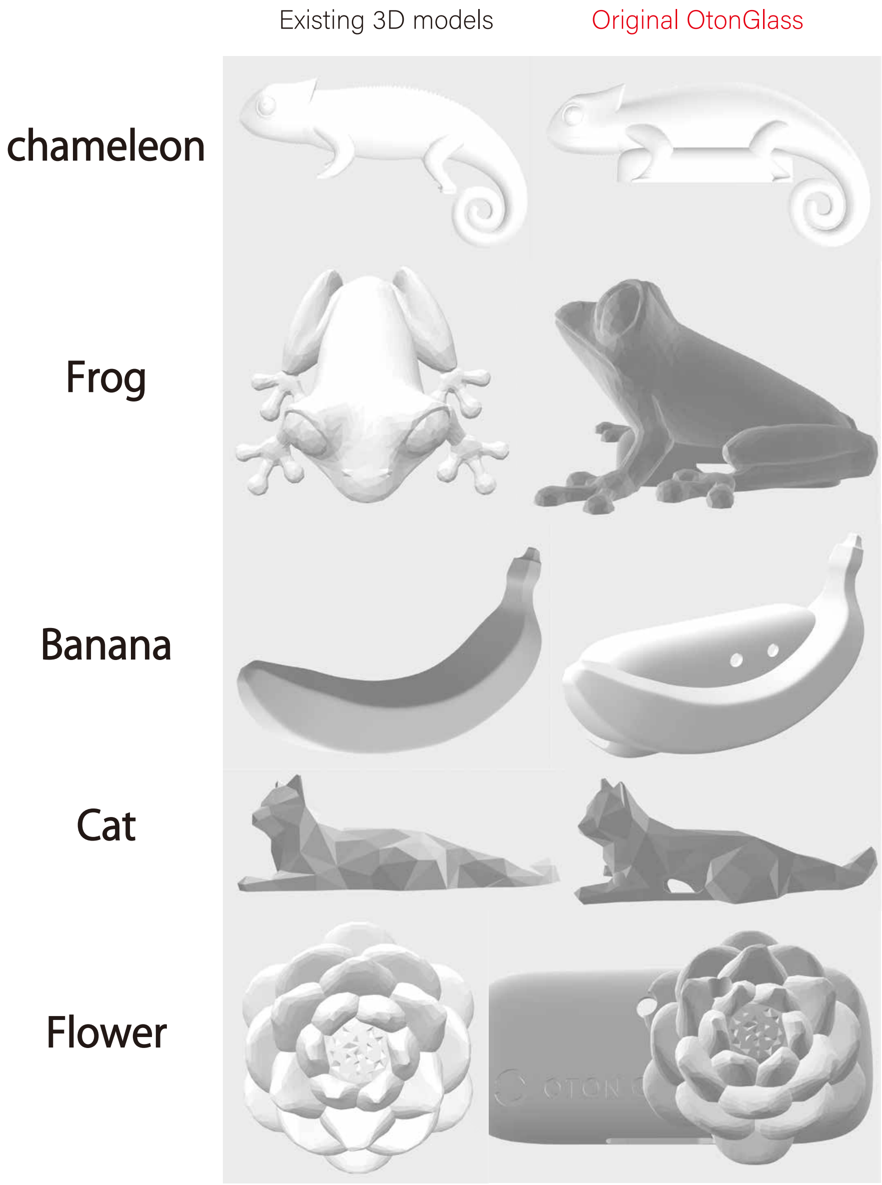

Figure 4.4: There are some samples of OtonGlass we created berorehand. Its lineup here is chameleon, frog, banana, cat, and flower.

Figure 4.5: Some situations of this workshop. In this workshop, I firstly introduced the students what OtonGlass is and how to customize the design on Fusion 360, which is a famous 3D CAD software.

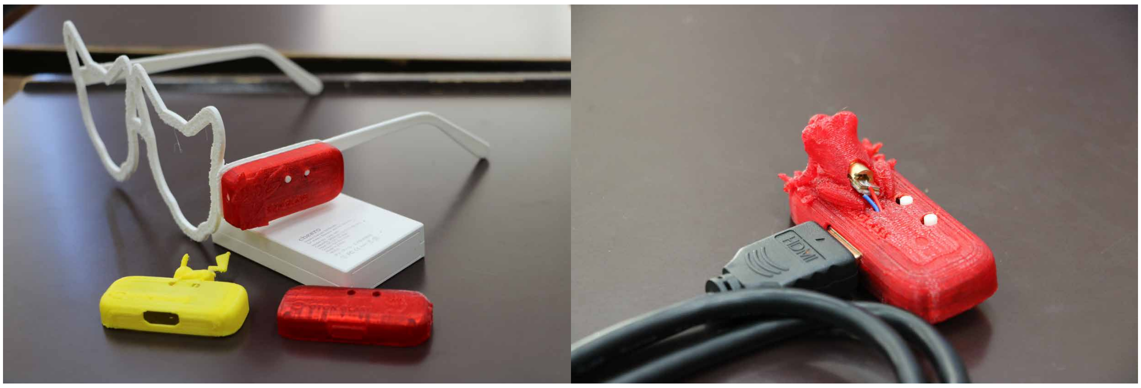

Figure 4.6: In this workshop, participants created some kinds of OtonGlass based on their aesthetics.

4.4.1 Participants

As shown in Figure 4.5, we held the workshop in the class, OpenDesign, at Keio University, Shonan Fujisawa Campus(SFC). This workshop is for international students who are familiar with 3D computer-aided design softwares, and twelve participants from different countries participated in this user study.

4.4.2 Experimental Procedure

In this workshop, subjects design the 3D model of the cabinet of OtonGlass on Fusion360, the notable CAD softwares, and actually print it out by 3D printers. Through designing that, we evaluate qualitatively how assistive device designed based on user's aesthetics have important meaning for personalization and how affinity these device have as is the case with general grasses-type devices such as eyeglasses or sunglasses. As the evaluation, We analyzed the scores of each question on a 7-point Likert scale.

# Questionnaires regarding usability	Mean	SD	%
1. You hope visually impaired people use this device.	6	1.73	4/5
2. You hope to use this device if you are visually impaired people.	4.75	1.28	7/8
3. The design of this device has a potential to be useful as a tool for emotional expression.	5.2	1.64	4/5
4. The design of this device has diversity.	5.2	1.64	4/5
5. You can realize the design with your aesthetics more If you can make use of various materials or 3d-printing technologies.	6.6	0.55	5/5

Table 4.1: Results from workshop questionnaires regarding usability. (1 = Strongly disagree, and 7 = Strongly agree)

4.5 Results

Our goal was to let non-novices of engineering and product design customize OtonGlass, which aim to create opened platform as a toolkit, by themselves, and then reveal how potentials these devices have for improvement of the usability of visually impaired people. In this section, we show the itemized results from questionnaires, and some comments. Also, the secondary objective of this user study is to establish guidelines for the design of the original design process in the future by evaluating how the design process presented in this user study constrains their creativity.

4.5.1 Usability

As the investigation of usability, we prepared four questions below. Note that OtonGlass has been developed for visually impaired people, and then we will ask them to use aesthetic personalized OtonGlass as the next step. Therefore, we conducted both a subjective evaluation as how much they wanted to use it if they were visually impaired people, and an objective evaluation as how much they wanted the visually impaired people to use it.
Second, we asked them whether the device would function as a self-emotional expression tool. The background of this question is that glasses have been used not only as vision enhancement devices, but also as user's self-emotional expression tool. Its color and shape are main features to realize it, for example sunglasses can create a naturally cool atmosphere, and round glasses can create a naturally mild atmosphere. On the other hand, glass-type assistive device do not have these aspects because eventually their shape is unique.
Finally, we investigated the potential which this user study has. As revealed in section 4.5.3, this workshop targets not professional engineers, but non-novices of 3D-modeling. Therefore, whether they can work efficiently in their creation depend on what tools they select. Table 4.1 summarizes the results of the questionnaire that consisted of the mean, SD, and percentage of positive responses with scores >4 on a 7-point Likert scale. The mean of every item denotes positive results. However, there were mixed feelings on usability (Q1, 3, and 4) with relatively large SDs.

# Questionnaires regarding assumed scenarios	Mean	SD	%
2. There are already ready-made goods that match the scenario, and you can substitute it for what you fabricate by yourself.	5.25	1.71	3/4
3. You think that fabrication by myself fitted the scenario.	6	0.82	4/4

Table 4.2: Results from workshop questionnaires regarding assumed scenarios. (1 = Strongly disagree, and 7 = Strongly agree)

# Questionnaires regarding no assumed scenarios	Mean	SD	%
1. There is no discomfort even if it is used in a strict or formal place.	4	2.24	3/5
2. You would like to use it in an artistic place such as reading support of musical score when playing a musical instrument.	6.2	0.84	5/5
3. You would like to use it when communicating face to face with other people.	4.6	2.30	4/5
4. You would like to use it when doing desk work.	6	1	5/5

Table 4.3: Results from workshop questionnaires regarding no design applications which participants assumed. (1 = Strongly disagree, and 7 = Strongly agree)

4.5.2 Design Applications

We leave the design to their inspiration so as not them to assume beforehand that the product will be used in specific scenarios. However, we found several things that the design had a clear intention of the scenario in which they wanted to use it. Therefore, we conducted both scenario-based questionnaires and vice versa.

Specific Applications that Participants Assumed

When participants designed OtonGlass while assuming specific scenarios, we first asked them what the situation is, and then evaluated substitutability by ready-made goods in that scenario. Finally, we also queried them about how much their product fit the scenario. In addition, we asked for details with free-description questions. For example, P(Participant) 1 and P2 assumed to read notes through using the devices as is the case of conventional OtonGlass. Meanwhile, the assumed scenario of P3 and P6 was more concrete. They answered that then would use the devices when reading new music sheet to play music. New music sheet is certainly difficult for visually impaired people to be able to play the music smoothly. Table 4.2 summarizes the results of the questionnaire that consisted of the mean, SD, and percentage of positive responses with scores >4 on a 7-point Likert scale. The result of Q2 shows that participants tend to consider to substitute reading skills itself as ready-made goods such as cheaters. However, the products fabricated by themselves were sufficient to adjust their assumed scenarios as shown in the result of Q3.

# Questionnaires regarding design process using Fusion 360	Mean	SD	%
1. This design process is creative for designing an assistive device.	5.43	1.27	7/7
2. This design process is so simple that I focus on 3d-modeling.	4.43	1.62	5/7

Table 4.4: Results about effectiveness of design process. (1 = Strongly disagree, and 7 = Strongly agree)

No Specific Applications that Participants Assumed

We prepared some scenarios for participants who didn't assume any scenarios when designing OtonGlass, and then verified how much their product fit these scenarios. In addition, we asked for details with free-description questions. As the scenarios, we prepared strict formal place(Q1), artistic place(Q2), communication with other people(Q3), and desk work(Q4). Table 4.3 summarizes the results of the questionnaire that consisted of the mean, SD, and percentage of positive responses with scores > 4 on a 7-point Likert scale. As the result, participants donated positive results in Q2 and Q4, and vice versa in Q1 and Q3.

4.5.3 Effectiveness of Design Process

As mentioned above, We also need to verify whether the proposed design process for non-novices of 3D-modeling was simple enough for their creation.
Table 4.4 summarizes the results of the questionnaire that consisted of the mean, SD, and percentage of positive responses with scores >4 on a 7-point Likert scale. The result of Q1 showed that Instructional design process in this workshop did not lose their creativity. On the other hand, Q2 showed that given scores differed among respective participants. Q2 concerns the simplicity and asks them whether they can concentrate on 3D-modeling or not in that design process.
P(Participant)1: *Autodesk is hard to use if not trained.*
P2: *It was hard to deal with some errors.*
Participants commented on the reasons why it was simple to focus on 3D-modeling. From the above comment, we confirmed that they have only one favorite CAD software and are not familiar with anythings except for it.

Chapter 5

Discussion

In this chapter, we discuss both two strategies mentioned above and these remaining challenges in detail.

5.1 Physical Featured Personalization

5.1.1 Exo-Balancer

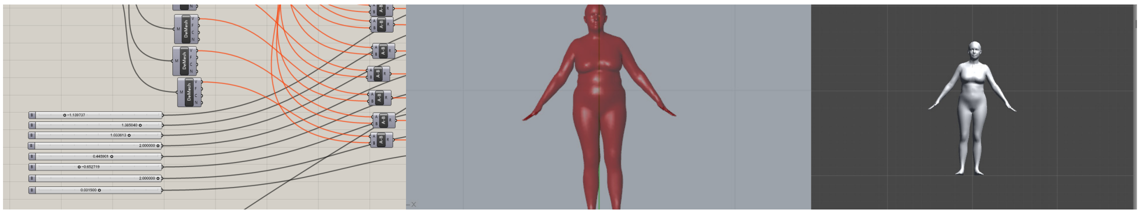

Figure 5.1: Left: 8 sliders imitating Body Talk to adjust the body shape. Users can easily change the shape of the 3D avatar by adjusting the value of each sliders. Center: edited 3D avatar image shown on Rhinoceros. Right: Mesh data of the 3D avatar which is sent to Unity on real time in order to utilize for physical simulations while changing it on Rhinoceros.

Through the user study, we asked participants and verified the usability and enjoyability. As the result, we found what we should improve: reselection of equipments and expansion of the kind of experimental situations. Our quantitative evaluation revealed that method C was the most appreciated one. Method C is minus 5 cm from the value of x, which was calculated, and the reason why participants appreciated it can be considered owing to a harness. In our experiment, we used a rubber harness because we want to detract from participants' wearability and keep their lightness as much as possible. However, a rubber can expands and contracts easily, therefore a monopod was fixed slightly looser than the simulated result in method A. As the result, the scored of a 5-point Likert scale revealed that method C is most appreciated by participants. An another limitation for this study is that our instrument cannot cover all participants. x was a few cm larger or smaller than the range that our instrument handles when we experimented one strapping man and one smallish woman. From now on, Fundamental reselection of the ready-made instruments or making them by ourselves using digital fabrication tools such as a 3D printer and laser cutter may lead to enhancements of the usefulness.

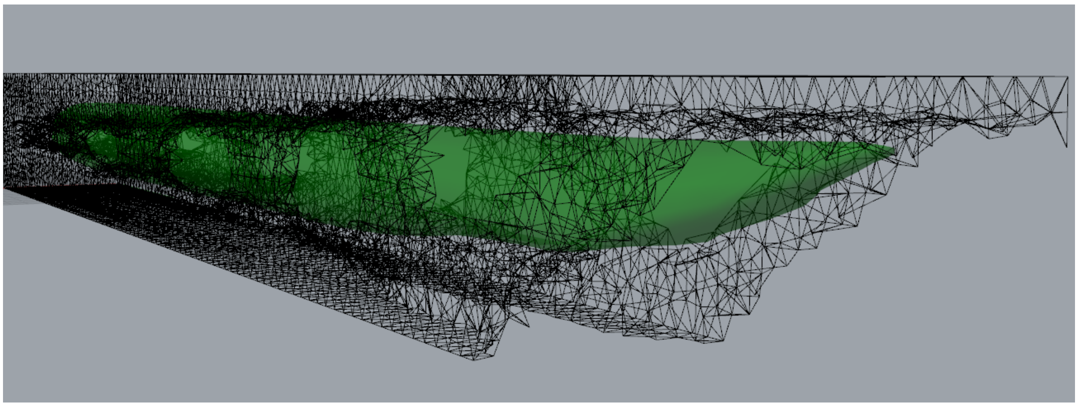

Figure 5.2: Wireframes show the meshes of 3D model on which we conducted topology optimization, and its inside 3D model shows the one after laplacian smoothing.

Meanwhile, through our qualitative evaluation, holding a camera with participants' hand reduce the shake most. Our study is at the prototype stage of achieving the personalized design method, therefore we focus on exploring the design method for personalization to augment user body and enriching user experiences more. Thus, we now do not focus on stabilizing more than existing stabilizers. However, the prototype we presented in this paper may be sometimes useful, for instance, when the user take a photo under the circumstance that you are unsteady on your feet. We conclude that this approach shows great promise to be useful under such situations and improve the performance as a stabilizer.

5.1.2 Design Method of Ergonomically Personalized by Topology Optimization

As the next step of Exo-Balancer, We chose topology optimization for shape-optimization to realize the personalized stabilizer without altering the shape of fundamental stabilizer. Topology optimization for the structure we define in Figure 3.12 left can be limited when applied loads to supporting or load-bearing positions within the structure. In other words, it is desirable that these structures corresponding to user's physical characteristics. Therefore, we need to have several basic structures, and then we use the different one depending on each user. We will also attempt to develop the system with automatic parameter tweaking functions for designing personalized stabilizer. It is generally known that not only the topology optimization but also almost all shape-optimized models are often coarse and not practical. Therefore, it is necessary to smoothen such coarse parts on a model. Laplacian smoothing algorithm [7] is one of the algorithms to smoothen a polygonal mesh. According to the common recognition, we also smoothed our model. However, we tend to have more non-manifold edges in our models, therefore we could not conduct the process smoothly as shown in Figure 5.2. More practical design will require more strict smoothing process based on Laplacian algorithm.
We developed a camera mount for pitch directional stabilization, and it is used for compact camera. However, it does not function when you use a camera with heavy lens because the center of gravity shifts remarkably.

5.2 Hackable OtonGlass

Through the experiments, we found that personalized assistive device driven by user's own aesthetically significantly different in the usability and revealed some problems. In this section, we discuss them and future works.
OtonGlass has some constraint conditions about its cabinet design. First, button interfaces which a user push when he or she activate the camera in the cabinet of OtonGlass are on the side of the cabinet. He or she applies the cabinet vertical forces because the structure that he or she applies horizontal forces leads to the fluctuation of the glass itself, and it degrades the performance of OtonGlass as the assistive device. Therefore, we must keep the structural constraints when a user design it on a 3D CAD software. As the result, for example it is difficult attaching the 3D model onto the cabinet.
Second, we discuss about electronic devices in the cabinet of OtonGlass. A small web camera and a circuit board for activating it are laid inside the cabinet. Therefore, it is physically difficult to redesign the cabinet itself. However, it is possible to give a certain degree of freedom to the shape by substituting a conventional circuit board for a flexible one. Needless to say, its trial is not still efficient to take all visual aesthetic preferences of 3D model of OtonGlass into account, however the design of the attachment based on that free shape because of flexible circuit boards will definitely be widely deployed and will be able to meet more design needs.

5.3 Remaining Challenges

We have investigated design methods of personalization in two assumptions: Physical-based personalization and aesthetic-based personalization. To ease assumptions and make our methods more practical, there are a number of possible remaining challenges as next steps.

5.3.1 Advanced Topology Optimization

Our future work requires practical experiments for various shooting situations. We conducted the shooting experiment in advance, in which a photographer stood still while a target object was moving. On the contrary, we can consider a shooting situation in which only the photographer moves while the target object is stationary, such as capturing a picture in the same pose or scanning a static object with a 3D scanner. Both the photographer and target object are stationary in the shooting situation, such as when photographing a landscape, and vice versa, such as when photographing a running athlete. Thus, several shooting situations exist, and must recruit specific participants such that their photographic skills can be divided into three ranks: professional, semi-professional, and novices. We will be able to gain more useful results through such a type of comprehensive user study.

5.3.2 Augmentation of Everyday Materials

Augmentation is a fundamental approach to expand the existing concepts towards anew such as augmented reality (AR), Mixed Reality (MR), or augmented human (AH). In this thesis, we focused on designing only specific devices and could not realize the personalization on general everyday materials. Augmented everyday materials are often used to support

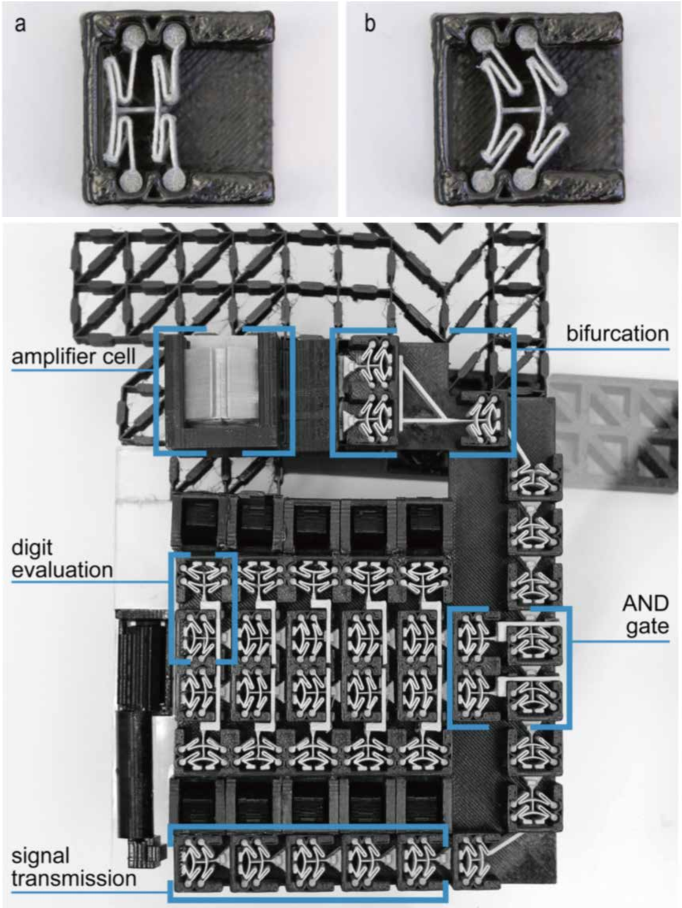

Figure 5.3: Design method of mechanical computation into 3D objects [11]. When it is triggered, this bit cell changes its state from tense to relaxed. By applying its structural features, they realized a door consists of a lot of cells, which implement the signal transmision.

a range of users [5]. Our method lets users to explore design space and then print it out by 3D printers. However, a recent augmentation approach of everyday materials revealed that enable to make 3D-printed objects deformable [10]. If we can do that, it makes our personalization method more flexible. Therefore, Augmentation of everyday materials is an interesting future work for us.

5.3.3 Externalization of Physical Interface

By externalizing physical user interface, developers can focus on what is required for their products. Researchers in different fields have externalized user interface. The simple way to externalize physical user interface is using smart devices such as smartphones, smartwatches, and so on. As we focused on only specific solutions, our method cannot handle general design such as physical interface. Externalized physical interface is interesting future works and it has been recently researched [24, 15, 9]. In particular, we realized that grasp can be a trigger to functionalize various ready-made goods, and the design method focused on that physical user interface has not been explored sufficiently.

Grasp-Based Personalized Physical Interface

Grasp is a fundamental physical user interface and it is in any equipments which needs to pull a trigger such as airgun, camera, or umbrella. Thus, the mechanism that something works with grasp has been applied to many industrial products while the shape with grasp is constant because of mass-product. For example, the hand of infants is too small. Females generally have weak grip strength, while the hands of males are often large and thick. Therefore, it occasionally happens that users cannot grasp the user interface when they want to do that. In that case, they are obliged to use it unwillingly or ask someone else instead of them because there is no definite solution.
To address the problem, we consider the design method of physical user interface based on connector to externalize physical user interface for grasp and personalize the shape optimization. However, this is still challenging because it is difficult to define how users hold or grasp mathematically. Ramekers et al.[36] presented an end-to-end design and fabrication environment that allows novices to retrofit physical interfaces. As the new physical interface, Koyama et al. [21] presented AutoConnect, a computationally optimized 3D-printanble connector which works between different two products. It enables all users to grasp and operate it easily. For example, females can pull a trigger of airgun easily and infants can activate a camera shutter. Thus, we expect to update how to use ready-made goods spectacularly. One realistic solution is to mechanically physical interface as the work by Ion et al [11].

5.4 More Applicable Design in Some Scenarios

As the future works of redesigning an assistive device as favorite one for users, we must firstly consider how to expand the attachment. Conventional OtonGlass is only applicable to limited glasses, designing attachments have been researched in some ways [5]. we will be able to make OtonGlass more applicable to some kinds of glasses by applying these knowledge to our method. Furthermore, 3D-printing technologies can use some materials, therefore we can improve OtonGlass more from the viewpoint of aesthetics. For example, we can create some scenarios where colorful chameleons are on a wooden glass, a glass with seven colored notes will not only support the blind pianist's performance by reading musical scores, but also make it more gorgeous visually or by utilizing wood 3D printing and dual printing.

5.5 Design Platform for Assistive Device

Besides, some participants in this workshop said that "we do not want to 3D-modeling on Fusion360, but on Rhinoceros" because each 3D CAD softwares force users subtle different expertises. In order to break down barriers for these softwares with different expertises, we need to build a design platform for designing aesthetic assistive devices. Because of the high affinity between design repositories on the Internet and novices of 3D-modeling, some researches of design platforms have been deployed on the cloud. As our next step, it is necessary to optimize a design platform to design an assistive device that integrate the programmatic environment that even end-users can deal and a cloud-based design repository

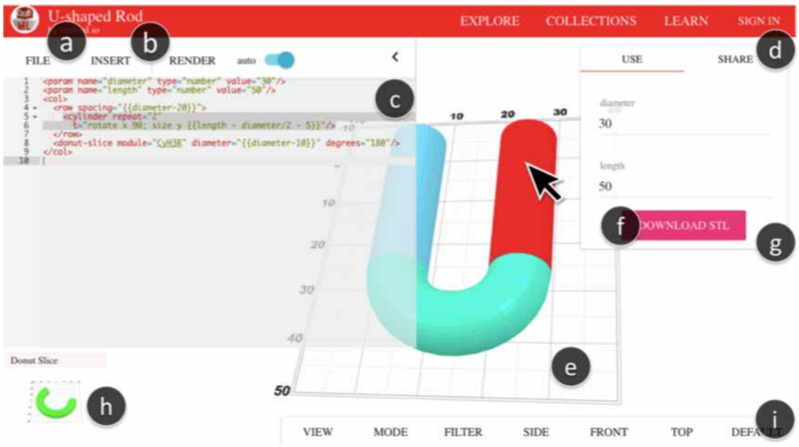

Figure 5.4: Cloud-based design platform[47]. CraftML offers a rich set of programming features familiar to web developers of all skill levels. This design plarform also function as design repository. It is easily accessible to CraftML users and share both the model and its programming code.

that enables all users to share 3D models they created such as CraftML [47].

Chapter 6

Conclusion

Our goal was to realize the personalization by digital fabrication. In this thesis, we verified the effectiveness of personalization with Digital Fabrication. First, we focused on personalizing stabilizer based on user's physical features. Stabilizer is a typical instrument for supporting photographer in photography and videography, and it has been used only by professional photographers because it requires high proficiency and costs. Through the basic experiment with our prototyping, we found some advantages of our method, and vice versa.
Then, we subsequently presented the design method of personalized stabilizer by topology optimization. Our primary contribution was to design personalized stabilizers through topology optimization method to establish an end-to-end design framework that removed materials efficiently and render stabilizers 3D- printable. As a sub-contribution, we designed a fundamental structure for the pitch directional stabilization of compact devices on which a camera was installed, such as smartphones. A comprehensive user study of camera users of different photographic skills in several shooting situations will be performed in the future. In addition, we will compare our method to conventional photographic methods such as commercial stabilizers or hand-held camera photography.

On the other hand, we also attempted to conduct another personalization. Assistive device was mature to a certain degree in technical aspect, meanwhile it has not still been mature in design. In this thesis, we collaborate with Keisuke Shimakage and designing OtonGlass, an assistive device for visually impaired people, more aesthetic driven by users. We held a workshop and instruct how to redesign the OtonGlass on Fusion 360, a notable 3D CAD software, to the non-novices of 3D-modeling. Through the experiment, we found that users tend to accept aesthetic-based design.

Acknowledgement

My deepest gratitude goes to my supervisor, Yoichi Ochiai, whose advice is always very smart and intellectually stimulating for me. I have learned really a lot from him during this two years, from ways to conduct successful research projects to ways of artistic activities. I would also like to thank him for providing me with many opportunities which are not limited to academic field.
I am grateful to my sub-supervisor, Norihiko Uda, whose heart-warming encouragement always relax me. I also thank to my another Thesis Committee members: Sarcar Sayan, for his thoughtful comments for improving this thesis.
I really like our laboratory, Digital Nature Group, and I would like to thank all the lab members. Especially, I greatly thank my co-authors, Kazuki Takazawa, who always encourages me as the second author of my papers, Kenta Yamamoto for both serious and casual discussions about what research is, and Riku Iwasaki for supporting my first international paper. When writing my first international paper, advices by Yuki Koyama, who is a researcher at National Institute of Advanced Industrial Science and Technology *AIST* were really stimulating for me. I have learned how to write a good paper from the research collaborations with intelligent lab alumni: Mose Sakashita and Akira Ishii. Regarding the English proofreading, I really appreciate the work of Bektur Ryskeldiev and Ooi Chun Wei. I also appreciate Pixie Dust Technologies.inc, for supporting our laboratory.
It was really beneficial for me to participate in xdiversity, the JST CREST project, and have the experience there to return profits from technlogies to society. All the experiences in xdiversity project were exciting for me. Especially, I have been motivated by Tatsuya Honda, Yuri Nakano, Yusuke Sugano, and Ken Endo. I was always inspired by their academic activities whose field is different to me.
Finally and most importantly, I deeply thank to Nanase Nishino, who was my most favorite member in Nogizaka46. Without her smile, I could not have finished writing this thesis and maintained my motivation for this two years.

References

[1] Aage, N., Amir, O., Clausen, A., Hadar, L., Maier, D., and Søndergaard, A. Advanced topology optimization methods for conceptual architectural design. In *Advances in Architectural Geometry 2014* (Cham, 2015), P. Block, J. Knippers, N. J. Mitra, and W. Wang, Eds., Springer International Publishing, pp. 159–179.

[2] Ates, H. C., Fiannaca, A., and Folmer, E. Immersive simulation of visual impairments using a wearable see-through display. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, 2015), TEI '15, ACM, pp. 225–228.

[3] Azenkot, S., and Zhao, Y. Designing smartglasses applications for people with low vision. *SIGACCESS Access. Comput.*, 119 (Nov. 2017), 19–24.

[4] Billinghurst, M., Clark, A., Lee, G., et al. A survey of augmented reality. *Foundations and Trends® in Human–Computer Interaction 8*, 2-3 (2015), 73–272.

[5] Chen, X. A., Kim, J., Mankoff, J., Grossman, T., Coros, S., and Hudson, S. E. Reprise: A design tool for specifying, generating, and customizing 3d printable adaptations on everyday objects. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (New York, NY, USA, 2016), UIST '16, ACM, pp. 29–39.

[6] Chen, X. A., Tao, Y., Wang, G., Kang, R., Grossman, T., Coros, S., and Hudson, S. E. Forte: User-driven generative design. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2018), CHI '18, ACM, pp. 496:1–496:12.

[7] Field, D. A. Laplacian smoothing and delaunay triangulations. *Communications in applied numerical methods 4*, 6 (1988), 709–712.

[8] Furukawa, H., and Tajima, A. Image stabilizing optical system having a variable prism, Mar. 9 1976. US Patent 3,942,862.

[9] Gannon, M., Grossman, T., and Fitzmaurice, G. Exoskin: On-body fabrication. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2016), CHI '16, ACM, pp. 5996–6007.

[10] Groeger, D., Chong Loo, E., and Steimle, J. Hotflex: Post-print customization of 3d prints using embedded state change. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2016), CHI '16, ACM, pp. 420–432.

[11] Ion, A., Wall, L., Kovacs, R., and Baudisch, P. Digital mechanical metamaterials. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), CHI '17, ACM, pp. 977–988.

[12] Johnson, L. A., and Higgins, C. M. A navigation aid for the blind using tactile-visual sensory substitution. In *Engineering in Medicine and Biology Society, 2006. EMBS'06. 28th Annual International Conference of the IEEE* (2006), IEEE, pp. 6289–6292.

[13] Kane, S. K., Frey, B., and Wobbrock, J. O. Access lens: A gesture-based screen reader for real-world documents. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2013), CHI '13, ACM, pp. 347–350.

[14] Kato, J., and Goto, M. F3.js: A parametric design tool for physical computing devices for both interaction designers and end-users. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (New York, NY, USA, 2017), DIS '17, ACM, pp. 1099–1110.

[15] Kato, K., and Miyashita, H. Extensionsticker: A proposal for a striped pattern sticker to extend touch interfaces and its assessment. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (New York, NY, USA, 2015), CHI '15, ACM, pp. 1851–1854.

[16] Kato, N., Osone, H., Sato, D., Muramatsu, N., and Ochiai, Y. Deepwear: A case study of collaborative design between human and artificial intelligence. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, 2018), TEI '18, ACM, pp. 529–536.

[17] Kawamura, R., Takazawa, K., Iwasaki, R., Yamamoto, K., and Ochiai, Y. Exo-balancer: Design method of personalized stabilizers for shooting actions. In *Proceedings of the 9th Augmented Human International Conference* (New York, NY, USA, 2018), AH '18, ACM, pp. 32:1–32:2.

[18] Kazi, R. H., Grossman, T., Cheong, H., Hashemi, A., and Fitzmaurice, G. Dreamsketch: Early stage 3d design explorations with sketching and generative design. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2017), UIST '17, ACM, pp. 401–414.

[19] Ko, S.-J., Lee, S.-H., Jeon, S.-W., and Kang, E.-S. Fast digital image stabilizer based on gray-coded bit-plane matching. *IEEE Transactions on Consumer Electronics 45*, 3 (1999), 598–603.

[20] Koyama, Y., Sakamoto, D., and Igarashi, T. Selph: Progressive learning and support of manual photo color enhancement. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2016), CHI '16, ACM, pp. 2520–2532.

[21] Koyama, Y., Sueda, S., Steinhardt, E., Igarashi, T., Shamir, A., and Matusik, W. Autoconnect: Computational design of 3d-printable connectors. *ACM Trans. Graph. 34*, 6 (Oct. 2015), 231:1–231:11.

[22] Langlotz, T., Sutton, J., Zollmann, S., Itoh, Y., and Regenbrecht, H. Chromaglasses: Computational glasses for compensating colour blindness. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2018), CHI '18, ACM, pp. 390:1–390:12.

[23] Lausegger, G., Spitzer, M., and Ebner, M. Omnicolor–a smart glasses app to support colorblind people. *International Journal of Interactive Mobile Technologies (iJIM) 11*, 5 (2017), 161–177.

[24] Leen, D., Ramakers, R., and Luyten, K. Strutmodeling: A low-fidelity construction kit to iteratively model, test, and adapt 3d objects. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2017), UIST '17, ACM, pp. 471–479.

[25] Lévy, P., and Yamada, S. 3d-modeling and 3d-printing explorations on japanese tea ceremony utensils. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, 2017), TEI '17, ACM, pp. 283–288.

[26] Lo, J., Torres, C., Yang, I., O'Leary, J., Kaufman, D., Li, W., Dontcheva, M., and Paulos, E. Aesthetic electronics: Designing, sketching, and fabricating circuits through digital exploration. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (New York, NY, USA, 2016), UIST '16, ACM, pp. 665–676.

[27] Markowitz, M., Daibert-Nido, M., and Markowitz, S. N. Rehabilitation of reading skills in patients with age-related macular degeneration. *Canadian Journal of Ophthalmology 53*, 1 (2018), 3 – 8.

[28] Marks, J., Andalman, B., Beardsley, P. A., Freeman, W., Gibson, S., Hodgins, J., Kang, T., Mirtich, B., Pfister, H., Ruml, W., Ryall, K., Seims, J., and Shieber, S. Design galleries: A general approach to setting parameters for computer graphics and animation. In *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques* (New York, NY, USA, 1997), SIGGRAPH '97, ACM Press/Addison-Wesley Publishing Co., pp. 389–400.

[29] Oshima, M., Hayashi, T., Fujioka, S., Inaji, T., Mitani, H., Kajino, J., Ikeda, K., and Komoda, K. Vhs camcorder with electronic image stabilizer. *IEEE Transactions on Consumer Electronics 35*, 4 (1989), 749–758.

[30] Pan, P., and Yanchong, Z. Connecting device and a gimbal apparatus, May 23 2017. US Patent 9,657,897.

[31] Peli, E. Vision multiplexing: an engineering approach to vision rehabilitation device development. *Optometry and Vision Science 78*, 5 (2001), 304–315.

[32] Peli, E., Luo, G., Bowers, A., and Rensing, N. Applications of augmented-vision head-mounted systems in vision rehabilitation. *Journal of the Society for Information Display 15*, 12 (2007), 1037–1045.

[33] Prévost, R., Bächer, M., Jarosz, W., and Sorkine-Hornung, O. Balancing 3d models with movable masses. In *Proceedings of the Conference on Vision, Modeling and Visualization* (Goslar Germany, Germany, 2016), VMV '16, Eurographics Association, pp. 9–16.

[34] Prévost, R., Whiting, E., Lefebvre, S., and Sorkine-Hornung, O. Make it stand: Balancing shapes for 3d fabrication. *ACM Trans. Graph. 32*, 4 (July 2013), 81:1–81:10.

[35] Querin, O., Steven, G., and Xie, Y. Evolutionary structural optimisation (eso) using a bidirectional algorithm. *Engineering computations 15*, 8 (1998), 1031–1048.

[36] Ramakers, R., Anderson, F., Grossman, T., and Fitzmaurice, G. Retrofab: A design tool for retrofitting physical interfaces using actuators, sensors and 3d printing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2016), CHI '16, ACM, pp. 409–419.

[37] Rousso, M. I. B., and Peleg, S. Recovery of ego-motion using image stabilization.

[38] Shen, W., Mao, X., Hu, X., and Wong, T.-T. Seamless visual sharing with color vision deficiencies. *ACM Trans. Graph. 35*, 4 (July 2016), 70:1–70:12.

[39] Shi, J., et al. Good features to track. In *Computer Vision and Pattern Recognition, 1994. Proceedings CVPR'94., 1994 IEEE Computer Society Conference on* (1994), IEEE, pp. 593–600.

[40] Shilkrot, R., Huber, J., Meng Ee, W., Maes, P., and Nanayakkara, S. C. Fingerreader: A wearable device to explore printed text on the go. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (New York, NY, USA, 2015), CHI '15, ACM, pp. 2363–2372.

[41] Sukan, M., Elvezio, C., Oda, O., Feiner, S., and Tversky, B. Parafrustum: Visualization techniques for guiding a user to a constrained set of viewing positions and orientations. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2014), UIST '14, ACM, pp. 331–340.

[42] Tanuwidjaja, E., Huynh, D., Koa, K., Nguyen, C., Shao, C., Torbett, P., Emmenegger, C., and Weibel, N. Chroma: A wearable augmented-reality solution for color blindness. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (New York, NY, USA, 2014), UbiComp '14, ACM, pp. 799–810.

[43] Terry, M., and Mynatt, E. D. Side views: Persistent, on-demand previews for open-ended tasks. In *Proceedings of the 15th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2002), UIST '02, ACM, pp. 71–80.

[44] Umetani, N., Koyama, Y., Schmidt, R., and Igarashi, T. Pteromys: Interactive design and optimization of free-formed free-flight model airplanes. *ACM Trans. Graph. 33*, 4 (July 2014), 65:1–65:10.

[45] Wang, L., and Whiting, E. Buoyancy optimization for computational fabrication. *Comput. Graph. Forum 35*, 2 (May 2016), 49–58.

[46] Xie, Y. M., and Steven, G. P. Basic evolutionary structural optimization. In *Evolutionary Structural Optimization*. Springer, 1997, pp. 12–29.

[47] Yeh, T., and Kim, J. Craftml: 3d modeling is web programming. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2018), CHI '18, ACM, pp. 527:1–527:12.

[48] Yi, C., and Tian, Y. Assistive text reading from complex background for blind persons. In *Camera-Based Document Analysis and Recognition* (Berlin, Heidelberg, 2012), M. Iwamura and F. Shafait, Eds., Springer Berlin Heidelberg, pp. 15–28.

[49] Young, V., Querin, O. M., Steven, G., and Xie, Y. 3d and multiple load case bi-directional evolutionary structural optimization (beso). *Structural optimization 18*, 2-3 (1999), 183–192.

[50] Zhao, Y., Hu, M., Hashash, S., and Azenkot, S. Understanding low vision people's visual perception on commercial augmented reality glasses. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), CHI '17, ACM, pp. 4170–4181.

[51] Zhao, Y., Szpiro, S., and Azenkot, S. Foresee: A customizable head-mounted vision enhancement system for people with low vision. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (New York, NY, USA, 2015), ASSETS '15, ACM, pp. 239–249.

[52] Zhao, Y., Szpiro, S., Knighten, J., and Azenkot, S. Cuesee: Exploring visual cues for people with low vision to facilitate a visual search task. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (New York, NY, USA, 2016), UbiComp '16, ACM, pp. 73–84.