3D Printed Sleep Mask

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ABSTRACT

This project explores the development of a highly customizable face mask utilizing 3D scanning and fabrication technologies. Motivated by the limitations of conventional mask design and the desire for personalized comfort, our team employed the KIRI Engine for 3D facial scanning and implemented a computational approach using the face recognition and PIL libraries to identify facial landmarks and create a tailored mask design. The masks were fabricated using various materials tested for their suitability, including TPU and PLA, with the final prototypes printed in TPU 92a due to its optimal properties of flexibility and durability. User experience was assessed through systematic testing involving four participants, focusing on criteria such as smoothness, weight, light coverage, and flexibility. The findings indicate a strong preference for a particular mask design, highlighting the effectiveness of our approach in producing masks that cater to individual physical features and comfort needs.

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1 PROBLEM STATEMENT

The face masks commercially available in the market are designed for the majority of people, which means some users may have a hard time finding the best face mask that suits the shape of their face. Our team aims to utilize 3D scanning and 3D fabrication to produce highly customizable face masks tailored for individuals, allowing users to choose the appearance of their sleeping masks.

2 MOTIVATION AND RELATED WORK

The inspiration for this project comes from a blog written by Joe M[1], where he creates a customizable face mask by pouring a mixture of silicone caulk and cornstarch in between two 3D printed molds built from his 3D face scan. The blog highlights three drawbacks to this approach: the mask emits a heavy odor due to the material choice, it requires additional post-processing to make it safe for direct contact with the face, and the quality of the mask heavily depends on the infill rate of the mixed materials, leading to an unstable production rate. This motivation has guided our team to explore a more direct approach by using a 3D scanned model of an individual's face to create the mask, thereby bypassing the need for a facemask mold. This process not only promises a better fit but also minimizes the discomfort and potential health risks associated with indirect mold-making methods.

3 3D SCANNING APPROACH

The software used for 3D scanning in our project is KIRI Engine, which is available across multiple platforms. All scans throughout the project have been conducted using the same device (iPhone 13 Pro). KIRI Engine offers multiple 3D scanning approaches, ranging from LiDAR, photo scan, to 3DGS. Through trials and errors, photo scanning stood out, showing high details and stability among others, with each body scan produced from 160 images taken by the app.

4 COMPUTATIONAL APPROACH

Using the KIRI Engine, we first obtain an individual's 3D facial model. This model is then transformed into a 2D frontal snapshot—a critical step, as it provides a standardized view for subsequent image processing and mask design. Utilizing the face recognition library, we can identify detailed facial features from this 2D image, such as eyebrows, eyes, and the nose.

From this 3D model, we created a program that for an input of a jpeg file of the front face of the 3D scan, the program returns the same photo with facial landmarks highlighted in small blue squares. These landmarks are eyes, tip of the nose, nose bridge, top part of the lips and the ears. Our program uses a deep learning library with facial landmarks to compare the jpeg file to the ones in the library and points out the facial landmarks of the input file. For this program to return correctly, the 3D scan must have the landmarks mentioned above with both eyes open and lips closed.

Next, employing the Image and ImageDraw modules from the PIL library, we define a polygonal area based on the detected facial landmarks. This area not only represents the portion of the face that the mask will cover but also serves to generate the 2D mask prototype. By creating a mask on the image and using it to crop the original facial snapshot, we obtain a precise mask shape. Additionally, the system calculates the coordinates of each polygon vertex relative to the center of the chin. These coordinate data are crucial for the subsequent manufacturing of the 3D mask. The generated 2D mask prototype can serve as both a schematic for the design and can be directly displayed in the user interface for further review and user interaction. This allows users to visually perceive the style of the mask to be produced and suggest modifications if necessary.

The ultimate goal of the current system is to apply these 2D prototypes and coordinate information to script 3D cutting operations that directly control the manufacturing process of the mask. Although this component has not yet been implemented, it is anticipated that such an automated process will significantly enhance the efficiency and customization level of mask production. Moving forward, we plan to develop the corresponding 3D cutting scripts to seamlessly bridge the gap from 3D scanning to final product delivery.

The entire process not only emphasizes the advancement and practicality of technology but also incorporates substantial user

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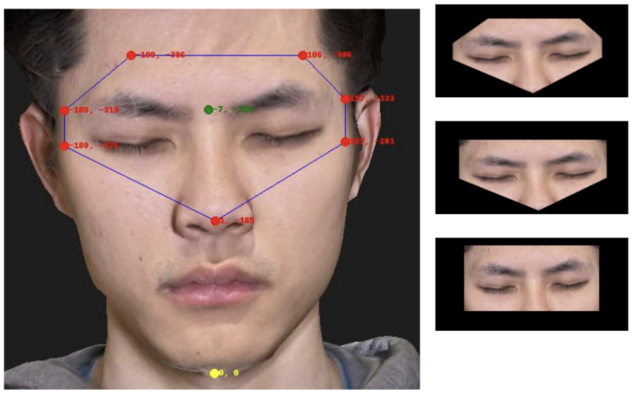

Figure 1: Placing landmark and create mask outline

interaction, ensuring that the final products precisely meet user requirements. With further development and refinement, this system is expected to find broad applications in the design and manufacturing of personalized masks.

We opted for 2D image processing over direct 3D model recognition due to the significant advantages in terms of simplicity and computational efficiency that 2D methodologies offer. We chose to leverage well-established and robust tools such as the face recognition and PIL libraries, which simplify the implementation of feature detection and image manipulations without necessitating extensive expertise in 3D modeling. Additionally, 2D operations require less computational power and storage, which translates into faster processing times. This aspect is particularly crucial for our interactive systems that integrate user feedback into the design process. On the other hand, working with 3D data introduces complexities related to mesh quality, data completeness, and the need for more sophisticated algorithms, potentially complicating development and increasing costs. Therefore, utilizing 2D images not only enhances the accessibility of the technology but also ensures greater efficiency in facial feature recognition and mask design for our applications.

5 COMPUTATIONAL CHALLENGES

We initially wanted to implement 3D automation of the mask and placing the landmarks but we failed on both of them. For the 3D automation of the mask, we tried to create the mask using 5-6 points (facial landmarks) on the 3D mesh; however, every 3D scan had different vertex for the landmarks and it was hard to manually pinpoint the middle of each landmarks because each landmarks had around 15-20 vertex and we could not decide on which one to use and the coordinates for each scans were different. We tried using Rhino, Blender, and MeshMixer to complete this challenge but we were not able to automatically create the mask. We found a showcase from Ellio Labs creating a sleep mask with automation using Blender[2] and thought we could also manage to create the automation but there was no information or research that was open-source and with multiple tries on our own, we could not complete it.

For placing landmarks on our 3D mesh, we also could not implement it on either obj or stl file. So we used a 2D implementation of finding landmarks using a deep learning library. There wasn't a deep learning library for 3D meshes nor any 3D scan related files. We managed to create a real-time facial landmarking tool that shows the landmarks using a javascript camera and a 2D (jpeg file) implementation of facial landmarking but not for the 3D files. We think that there still needs to be further research on creating a deep learning library for these 3D files and better algorithms to pinpoint the vertex exactly onto the middle of the landmarks.

6 FABRICATION APPROACH

In order to process our 3D scanned object produced by KIRI Engine, we utilize software named Rhinoceros (Rhino 8) 3D, which is a commercial 3D computer graphics and computer-aided design application software. Rhino 8 provides built-in mesh tools for post processing object files. To cut off the parts we need for producing facemasks, we utilize functions named "Mesh Box" and "Mesh Boolean Different" to isolate parts that are irrelevant. Mesh Box will let us create rectangle shaped mesh boxes to cover up unwanted areas. "Mesh Boolean Different" subtract the object and the parts that are covered by the rectangle shape mesh box. By leveling the object and the rectangle box, we were able to achieve a symmetry mask like object.

The surface of the object from our 3D scan is very rugged and uneven, creating a mask from uneven surface not only will be uncomfortable to wear when sleeping, it will also create a challenge for 3D printers to print and generate unnecessary and wasteful use for limited materials. To smoothen the surface, Rhino Commend "Smooth" provides options to smooth out one or multiple axes of the object that has been selected. After a number of trials and errors on all 3D scanned objects, "Smooth" command with input rate of 0.03 to 0.05 smooth factor per step, and 25 to 40 number of smooth steps will generate desired result, while not compromising too many details and characteristics of each 3D scanned object.

After the surface of the cut-out mask shaped parts has been smoothen, a few last steps to create a mask object is to repair meshing if needed and apply wrapping to the part. With all the process done to the 3D scanned object by far, the remaining part from the object is a single layer mesh surface that is formed by numerous triangle shape mesh and these remaining parts would usually be broken after the cutting and isolating. In order to move on to the next step, the mesh surface should be checked for completeness. Command named "MeshRepair" can be apply to the object to check if the object is healthy or is broken. "MeshRepair" provides a function to sort out problems from mesh - naked edges, degenerate faces, extremely short edges, duplicate faces, etc. – that were created during the previous process. Objects that are built without checking health may result in bad objects that will cause printing to fail in later production phases.

The last step of processing the object is to apply wrapping. "ShrinkWrap" command from Rhino can generate an object with desired thickness from a single layer mesh. With numerous testing and prototyping, masks with input value for Target Edge Length 0.01, offset of 0.01 and inflate vertices and points uncheck, will help achieve the middle point of final result softness, weight, and durability.

7 FABRICATION CHALLENGES

Numbers of materials and 3D printing approaches have been tested throughout the whole project. Material that has been used were resins PLA, SLA 50a, TPU 92a, and TPU 85a. PLA from MakerBot was the toughest among all materials that has been tested, it has been used for the first prototype which serves the purpose for sizing. SLA 50a provides the best flexibility and is the only one that has a certain level of transparency among all materials. The downside of SLA 50a was it has a strong odor, and the surface of the material is sticky. Using rubbing alcohol can reduce a certain amount of the stickless, but the smell will remain.

While TPU 92a provided the most stable printing success rate and is the most durable among all tested materials, TPU 85a from Siraya Tech has been tested which uses the same FDM approach but with better softness. The only printer that is available in the Engineering Product Innovation Center (EPIC) in Boston University which can print third party 3D printing filament is Bambu lab p1s. After few attempts to print the mask in TPU 85a, the print will always stop or failed at the exact slice of the object, which may due to the reason of soft material clogging the nozzle of the printer, even the printer can successfully print out a test print that was downloaded from Siraya Tech website.

TPU 92a was selected as the primary material for its stability and durability. The final product was lightweight, foldable, durable, and customizable to different facial scans. Due to time constraints, our team was only able to print one mask for each prototype.

Figure 2: five mask prototype ranging version 5,1,4,2,3 from the bottom

8 USER EXPERIENCE TESTING

The evaluation of user experience for our 3D printed face masks involved a systematic testing process with four participants. These individuals assessed the masks across four distinct criteria: smoothness, weight, light coverage, and flexibility, providing ratings on a scale from one to five. Our experiment encompassed five different mask shapes to ascertain which configuration best aligned with individual preferences and functional demands.

Table 1: User Choice of Mask

Tester	Smoothness	Weight	Coverage	Flexibility	Overall
Test1	3	5	5	4	5
Test2	2	5	3	5	5
Test3	3	5	3	4	5
Test4	5	5	3	5	5

The result was shown in Table 1. In terms of smoothness, versions 3 and 5 received the highest ratings, indicating better comfort and reduced friction against the skin. Notably, version 5 was consistently recognized for its optimal weight, as evidenced by a unanimous perfect score from all testers. Light coverage ratings varied, with version 5 excelling in one instance but showing variability in others; version 3 demonstrated consistent performance in this category. Regarding flexibility, versions 4 and 5 were deemed most adaptable, suggesting these designs accommodate facial movements more effectively without compromising fit.

Collectively, version 5 was distinguished as the preferred choice among participants, underscored by its comprehensive fulfillment of the evaluated attributes—lightweight composition, effective light obstruction, and enhanced flexibility and smoothness. This feedback is instrumental in guiding further refinements of our mask designs to better meet user needs and enhance overall satisfaction.

9 INDIVIDUAL CONTRIBUTIONS

Throughout the project, Qinfeng was responsible for researching and selecting 3D printing methods, fabricating post-processed 3D-scanned objects, prototyping various face mask shapes, and liaising with EPIC for the final 3D printing of the product. Yifei is responsible for fixing some computational problems such as trials for 2D implementations and 3D implementations. Attending the discussion to share some suggestions. Assist other team members to make masks.

Dayu explored various 3D scanning software and algorithms, ultimately selecting Kiri Engine's Photo Scan for all user facial scans due to its superior capabilities. Successfully completed the design and coding of the 2D automation program, which facilitated the facial recognition and mask design processes. Additionally, contributed to assisting with the design of the mask styles.

Seung Ki was responsible for implementing a real-time facial landmarking program and 2D (jpeg) facial landmarking program. Successfully implemented facial landmarking program and also tried implementing 3D mask automation but was not able to complete it.

10 CONCLUSION

This project successfully demonstrated the feasibility of fabricating a customized mask by integrating 3D scanning technology, computational design and advanced manufacturing methods. The final product, made primarily from TPU 92a, was validated through user experience testing, confirming its superiority in terms of comfort, fit and functionality. In particular, versions 3 and 5 of the mask ensured a high level of user satisfaction due to its excellent flexibility and smoothness. All in all, this project takes the potential of combining 3D technology with user-centered design to bring more possibilities for the personalization of wearable products.

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