UDC 004.94 : 617.581

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AN INDIVIDUAL MASK CREATION USING THE INFORMATION MODEL

В.М. Тігарєв, Ю.С. Барчанова, І.В. Прокопович, А.В. Лопаков, Р.А. Винокуров. **Створення індивідуальної маски з використанням інформаційної моделі.** Розробка індивідуальних засобів захисту дихання (маски) під час пандемії коронавируса актуальна. Сучасні технології проектування і виготовлення дозволяють створити маски з урахуванням індивідуальних анатомічних особливостей людини. У роботі розглянуто різні типи конструкції захисних масок. Необхідно створити маски з урахуванням анатомічних особливостей людини. Для вирішення цього питання в різних країнах проводяться конкурси зі створення масок нового покоління, такий як Mask Innovation Challenge в США. Ми пропонуємо створення захисної маски з використанням сучасних комп'ютерних технологій на основі інформаційної моделі. Розглянуто загальний підхід і варіант практичної реалізації створення маски з урахуванням індивідуальних особливостей людини. Інформаційна модель має 5 основних етапів створення захисної маски. Для створення моделі голови людини використано метод фотограмметрії, коли по двовимірним фотографіям формується її тривимірна модель. На поверхні моделі голови в програмі Autodesk 3DS Max створено основу каркасу маски за допомогою технології ретопології. Потім розроблено тривимірна твердотільна модель каркаса маски, яка перевірена на механічні навантаження при зміні міміки обличчя. Створення твердотільної моделі каркаса маски і симуляція механічних навантажень проводилися в програмі Autodesk Fusion 360. Проведено симуляцію виготовлення несучого каркаса маски за допомогою адитивної технології. Наприкінці створена маска з використанням змінного багатошарового фільтру. Подальшим розвитком роботи є проектування багаторазової маски з використанням різних типів фільтрів.
Ключові слова: каркас маски, інформаційна модель, твердотільна модель

V. Tigarev, Y. Barchanova, I. Prokopovych, O. Lopakov, R. Vinokurov. **An individual mask creating using the information model.** The development of individual respiratory protection (masks) during a coronavirus pandemic is relevant. Modern technologies of design and manufacture allow creating masks taking into account individual anatomical features of the person. The paper considers different types of construction of protective masks. It is necessary to create masks taking into account the anatomical features of the person. To address this issue, various countries are holding competitions to create a new generation of masks, such as the Mask Innovation Challenge in the United States. We offer creation of a protective mask with use of modern computer technologies on the basis of information model. The general approach and an option of practical realization of creation of a mask taking into account individual features of the person are considered. The information model has 5 main stages of creating a protective mask. To create a model of the human head, the method of photogrammetry is used, when its three-dimensional model is formed from two-dimensional photographs. On the surface of the head model in the program Autodesk 3DS Max created the basis of the mask frame using retopology technology. Then a three-dimensional solid model of the mask frame was developed, which was tested for mechanical loads when changing facial expressions. The creation of a solid model of the mask frame and simulation of mechanical loads were carried out in the program Autodesk Fusion 360. Fabrication of the supporting frame of the mask using additive technology is simulated. As a result, a mask is created using a replaceable multilayer filter. A further development of the work is the design of a reusable mask using different types of filters.
Keywords: mask frame, information model, solid model

Structured resume

The development of personal respiratory protection (masks) is currently very relevant during the coronavirus pandemic. Modern design and manufacturing technologies allow creating masks taking into account the individual anatomical characteristics of each person.

The paper discusses in detail various types of protective masks and their designs. The proposed designs of masks do not take into account the individual characteristics of each person. Therefore, there is an urgent need to create a mask, taking into account the anatomical features of any person. To resolve this issue, competitions are held in various countries to create new generation masks. An example is the competition held as part of the Mask Innovation Challenge in the United States.

DOI: 10.15276/opu.1.63.2021.10

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

We propose to create a protective mask using modern computer technologies based on an information model. A general approach and a possible option for the practical implementation of creating a mask, taking into account the individual characteristics of a person, are considered. The information model represents the 5 main stages of creating a protective mask.

To create a human head model, the photogrammetry method was used, when a three-dimensional model of a human head is formed from two-dimensional photographs. On the surface of a three-dimensional head model in Autodesk 3DS Max software, the base of the supporting frame of the mask is created using retopology technology. A 3D solid model of the mask's structural skeleton is then created. The developed supporting frame was tested for mechanical stress when changing facial expressions. Autodesk Fusion 360 was used to create a solid model of the mask's structural frame and simulate mechanical loads.

To consider the technology for creating the supporting frame of the mask, a simulation of manufacturing was carried out using additive technology on a 3D printer.

After the structural frame creating and testing, a mask was created using a replaceable multi-layer filter element.

A further development of the work will be the design of a reusable mask using options for various types of filters.

Introduction

The development of personal respiratory protection (masks) is currently very relevant during the coronavirus pandemic. Modern design and manufacturing technologies allow creating masks taking into account the individual anatomical characteristics of each person.

The creation of masks individually for each person is relevant not only during the development of a pandemic, but also for surgeons during operations, police officers on duty, etc. [1]

Analysis of recent research and publications

All personal protection products are divided into two large groups [2, 3]: disposable and reusable. If the former are used once and are immediately disposed of, the latter involve prolonged wear, for several months. Therefore, reusable masks have a low penetration rate and a higher cost.

Both types are used not only for personal purposes, but also in health care institutions, beauty salons, in industries and under the threat of man-made factors. In this regard, their extensive classification is distinguished.

Disposable masks are used in the field of medicine, cosmetology and in everyday life. The maximum wearing time of such a mask is no more than 2 hours, after which it must be replaced with a new one. Traditionally, it consists of an outer layer and a filter layer. Additionally, a hydrophobic layer or a film can be provided to protect the glasses from fogging. There are products with a flexible aluminum plate for tight fixation to the shape of the nose.

By the degree of filtration, disposable are divided into:
– two-layer – everyday masks with a protection degree of up to 98%;
– three-layer – for daily use, with a filter located in the center;
– four-layer – surgical products with protection against penetration of liquids.

By material of manufacture:
– cotton – using cotton filters;
– from spunbond – have high air permeability;
– from meltblown – with an inner filtering layer;
– self-made – made by yourself (from gauze, cotton, flax).

According to the availability of additional equipment:
– with valve – adjustable moisture outlet;
– without valve – the fabric has heat absorbing properties.

In addition to the classes considered, there are reusable masks that are more comfortable to wear and care for [4, 5]. They can be washed at high temperatures after each use without compromising the protective effect.

The so-called pitta mask is a tight-fitting filter made of polyurethane foam. It belongs to the reusable types and retains up to 90 % of pathogenic microparticles. This mask can be washed and used after drying, but not more than 2 months. The cost is significantly higher than the one-off options.

A filter mask can contain up to five levels of protection:

Level 1 (breathable molding layer) – blocks larger particles;

Level 2 (activated carbon) – adsorption of chemical and virological contaminants;

Level 3 (sprayed cotton) – filters small particles;

Level 4 – improved particle filtration;

Level 5 – non-woven breathable material.

In different countries, competitions are held to create new masks. For example, the US Government's Advanced Biomedical Research and Development Agency (BARDA), in conjunction with the National Institute for Occupational Safety and Health (NIOSH), has announced a competition to develop a "next generation mask" with a prize of 500,000 USD [6, 7].

The project was launched to solve several problems related to protective masks, including:

– fogging of glasses;
– skin irritation;
– inconvenience during prolonged wearing and also during communication;
– the risk of spreading COVID-19 due to a loose fit of the mask to the face.

The competition is held as part of the Mask Innovation Challenge program and consists of two stages.

The first phase focuses on design and is divided into two areas: one looks at improving existing masks, the other focuses on the use of new technologies and materials in their production. The submitted projects should include real proposals for the creation of new masks.

In the first stage, up to 10 winners will be determined, each of whom will receive 10,000 USD to create a prototype of their innovative mask.

The second stage is the creation of a new concept of the mask; its design must be completely new and original. The participants of the second stage of the competition will present prototypes of the author's masks for testing at the US National Institute for Occupational Safety and Health.

According to the results of the second stage, up to five winners will be determined; they will share the prize fund in the amount of 400 USD thousand.

Textile masks do not provide reliable protection against coronavirus, experts say. More effective means of protection against biological threats are respiratory masks, special filters and screens, and masks with special coatings. In the first year of the pandemic, many examples of innovative protective masks were developed in the world [5].

In the works [1 – 4], various types of masks are considered with the recommendations of specialists, but they do not take into account the individual characteristics of a person's face.

Our proposed approach corresponds to the second stage of the competition, namely the creation of a new mask concept.

The aim of the work is to create a protective mask taking into account the individual characteristics of a person using modern computer technologies based on a three-dimensional information model.

Main part

Currently, the creation of new objects in various fields, including medicine, is carried out using computer technology. To do this, you need to perform several successive stages of creating a mask. Several computer programs will be used to create the mask. When designing new objects using computer technology, it is important to use an information model. The information model generalizes the approach to design using various technologies, examples are presented in works [8 – 10]. To optimize the design process, it is proposed to use an information model for creating a mask, which will contain all the information on creating a mask. The information model consists of 5 main stages. Each of the stages consists of several sequential steps.

Let's consider in detail the description of the information model.

1. Stage – collection of information:

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

a) Determination of equipment for scanning (photogrammetry) of the investigated object;

b) Photogrammetry of an object and obtaining a mathematical model of the boundaries of the information model in the form of a point cloud.

2. Stage – formation and optimization of the face model:

a) Formation of the initial surface three-dimensional model of the human head object;

b) Elimination of form errors and optimization of the surface model of the face object.

3. Modeling the supporting structure of the mask:

a) Retopology of the supporting frame of the mask on the face surface;

b) Creates a model of the skeleton of the mask.

4. Shape analysis and simulation of loads on the mask structure:

a) Analysis of the shape and necessary loads for the created solid model of the mask;

b) Simulation of the required loads for a solid mask model.

5. Preparation of technology and production of a mask:

a) Designing the design of the mask taking into account the shape of the filter element;

b) Preparation of the technology for making a mask according to the created model;

c) Creation of a mask using the developed technology.

Let us consider in detail the general approach to creating a mask using the proposed information model.

At the first stage, to create a mask with an individual approach, it is necessary to obtain a 3D model of the head with the face of the person for whom this mask will be created. In this case, we are talking about the creation of a 3D model, the real analogue of which cannot have a clear drawing due to the unlimited number of unique parameters.

For such cases, 3D scanning and photogrammetry methods have been developed. The 3D scanning method requires special rather expensive equipment – 3D scanners. The photogrammetry method can be used for conventional smartphones. It consists in tracking points from different sources under the same conditions and creates a cloud of 3D points, which subsequently form the topology of the object.

Information about each photo is recorded in a special file: altitude, camera rotation angle, and longitude and latitude data. The program uses machine vision and photogrammetry technologies to find common points in many photographs. As a result, each pixel in the photograph has a color match in other photographs (Fig. 1) [11].

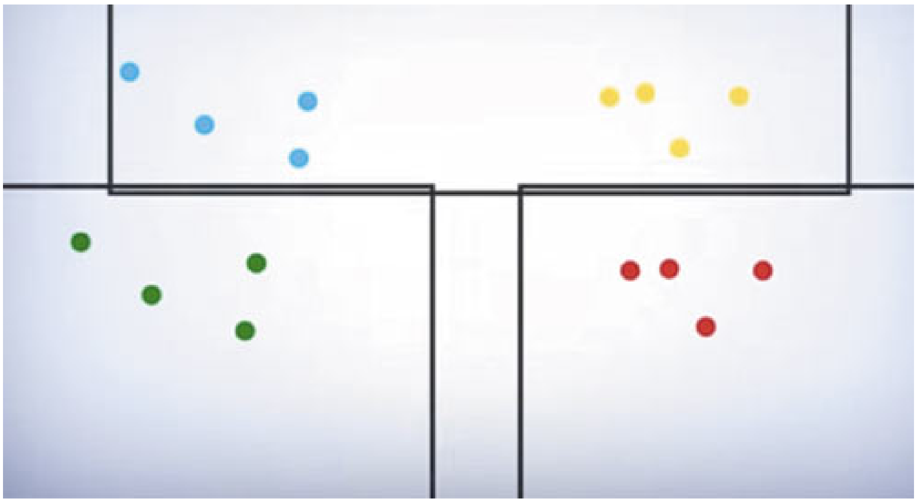


Fig. 1. An example of finding key points

Each match becomes a key point. If a key point is found in three or more photographs, the program builds this point in space. The more such points, the better the coordinates of the point in space are determined. Therefore, the more intersections between photos, the more accurate the model will be. An intersection of 60 to 80 % is optimal.

The spatial coordinates of each point are calculated by the triangulation method: a line of sight is automatically drawn from each survey point to the selected point, and their intersection gives the desired value (Fig. 2) [11].

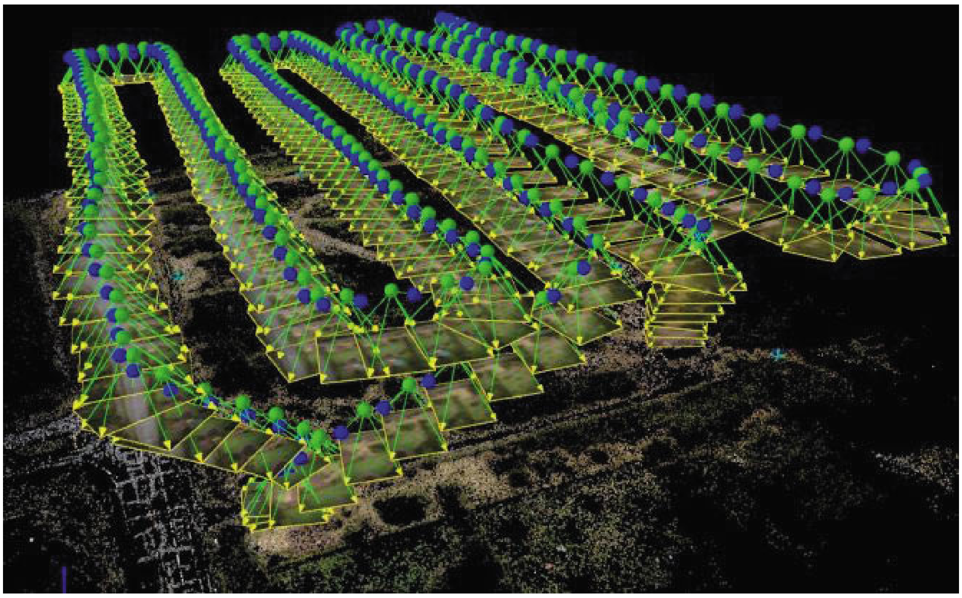


Fig. 2. Key points regarding the model

In addition, photogrammetry uses algorithms to minimize the sum of the squares of the set of errors. Usually, the Levenberg – Marquardt algorithm (or the bundle method) is used for the solution, based on the solution of nonlinear equations by the least squares method [12].

In the process of photo processing, an extended point cloud (a collection of all 3D points) is created, which is used to generate a surface composed of polygons. As a result, the resolution is calculated and it is determined which pixels in the photo correspond to which polygon. To do this, the 3D model is unfolded into a plane and then the spatial position of the point is matched to the original photograph to set the color.

For example, there is an object of a person's face. For the method to work, this face must be photographed from different angles under the same conditions: the same state of the object (facial expressions, position), the same environment of the object, its material. Maintaining these conditions guarantees a more productive search for the same point in different photographs, which will make it possible to more accurately display the shape of a face in a cloud of 3D points [13].

At the second stage, the photogrammetry program allows you to create a 3D model of the face. The resulting model must be placed in a program for processing three-dimensional models such as Autodesk 3DS Max, Maya. After that, the elimination of shape errors and optimization of the surface model of the face object is carried out, which will allow us to get the correct shape of the created object.

At the third stage, we carry out modeling of the supporting structure of the mask using the created face model. Therefore, we solve the inverse problem on the surface of the face and form the geometry of the future supporting structure of the mask. For this, the retopology toolkit will be used [14, 15, 16]. Retopology is the process of creating new geometry on top of the existing one, making changes to its structure. First, create a surface tangent to the face. Transfer the created mask base surface to CAD systems. We form a three-dimensional solid model of the mask's supporting frame in the selected CAD system.

At the fourth stage, we carry out the necessary shape analysis and simulate the loads on the mask structure. We set the type of material and its properties for the created solid model of the mask. Modern CAD systems allow simulating various types of loads for the created models. Conducting load studies is necessary in order to take into account the change in facial expressions during a conversation. In this case, the mask should fit snugly to the face.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

At the final fifth stage, we prepare the technology for making a mask.

First, you need to determine the type of filter element of the mask.

We offer a replaceable filter element that will be fixed on the supporting frame. The simplest version of a multi-layer filter element can be fixed temporarily using an adhesive layer. This will allow changing the filter element after 2 hours of operation. You can use the filter as in a pitta mask and rinse it in a disinfectant solution or using a separate filter.

When the type of filtering element is determined, we determine the manufacturing technology of the mask's supporting structure.

One of the most suitable is additive technology using a 3D printer. Currently, there are a large number of different types of 3D printers that use a variety of materials to form a product [17, 18].

We took a closer look at a general approach to creating a face shield using the information model.

Results

Let's consider the design of a protective mask using the information model using a specific example.

The information model for creating a protective mask in the form of a block diagram has the form (Fig. 3).

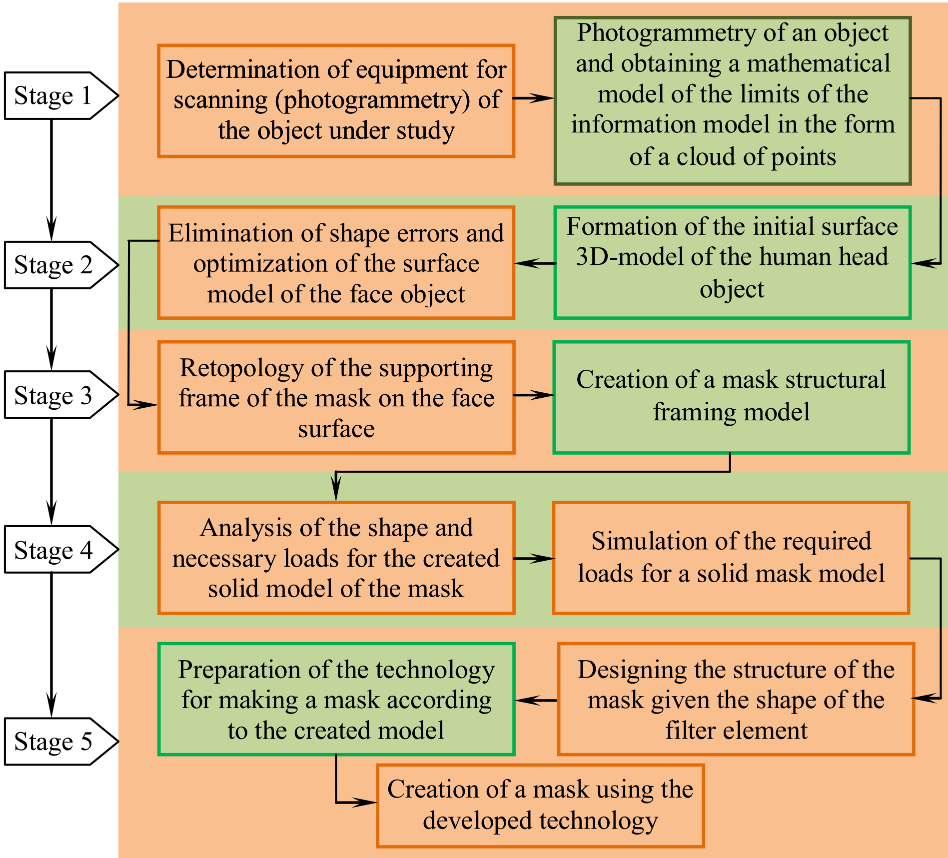


Fig. 3. Information model for the creation of a protective mask

At the first stage, we define a software product for performing photogrammetry. There are many programs for creating a three-dimensional head model using the photogrammetry method. We used the program Regard3D for work – this is a free open source photogrammetry program. To create a head model, 100 photographs were taken, with the help of which the boundaries of the model were determined and a point cloud of the future object was created. In Regard3D, we get a point cloud, on the basis of which we form a head model.

At the second stage, the point cloud was edited in the Regard3D program before sending it to generate a three-dimensional surface of the object. As a result of photogrammetry and point cloud correction, we obtain a three-dimensional surface model of the head (Fig. 4). Further head correction can be done in other software products such as Autodesk 3Ds Max.

Fig. 4. 3D surface model of the face

In the third stage, after the head model has been obtained, it is transferred to another software product (Autodesk 3Ds Max), where the development of the mask skeleton begins. For this, the retopology toolkit will be used. Retopology is the process of creating new geometry on top of the existing one, making changes to its structure.

Using the retopology tools, it is necessary to place the new geometry over the face, using it as a base (Fig. 5). This allows accurately positioning the new object and to continue to modify it. It is important to maintain the correct topology of the 3D model, which will be based on only quadrangles. This allows applying modifiers of subdivision of the model (Subdivide), which allows getting a multi-polygonal model with the ability to return to the previous state of the model and then adjust it, if necessary.

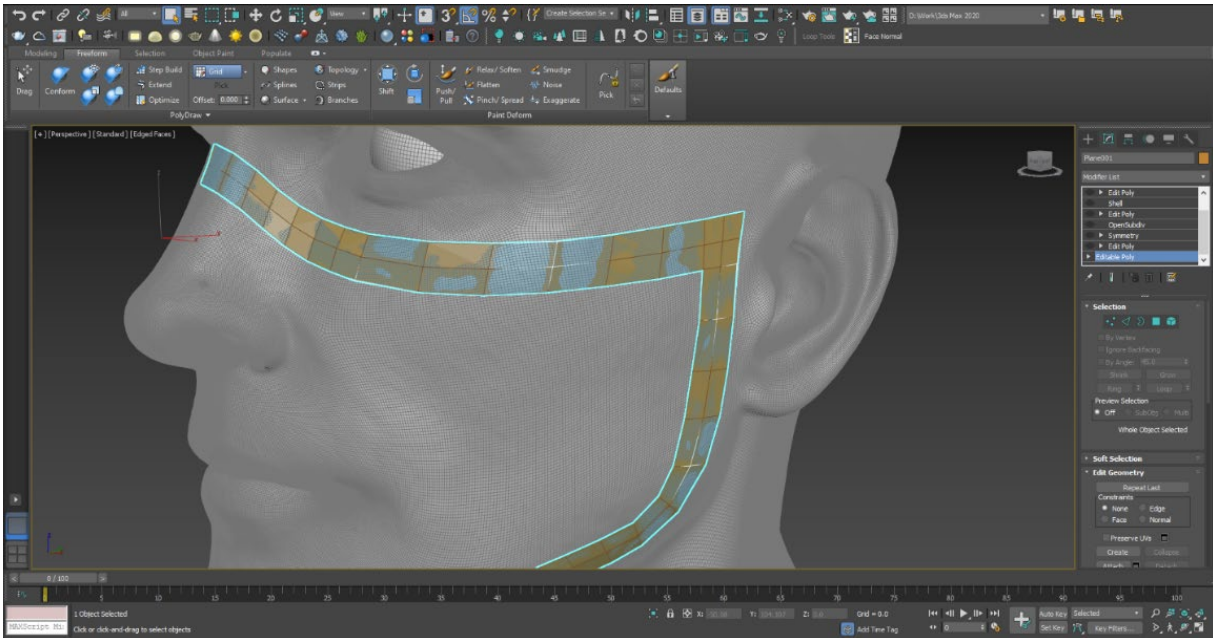


Fig. 5. Retopology of the mask frame

With this toolkit, the shape of the mask skeleton is created, which will be easy to change later. Using the resulting shape of the mask wireframe, create a solid (surface) model in Autodesk 3Ds Max (Fig. 6).

Such work with the topology of the model allows you to load the model into CAD modeling programs (in this case, we are talking about Autodesk Fusion 360), which opens up the possibility of performing various stress tests, assigning physical materials, creating settings for 3D printing, and much more. It is worth clarifying that any such program allows you to load a model, but this method differs in that the object is converted into the type of geometry that is supported by the program and allows further manipulations.

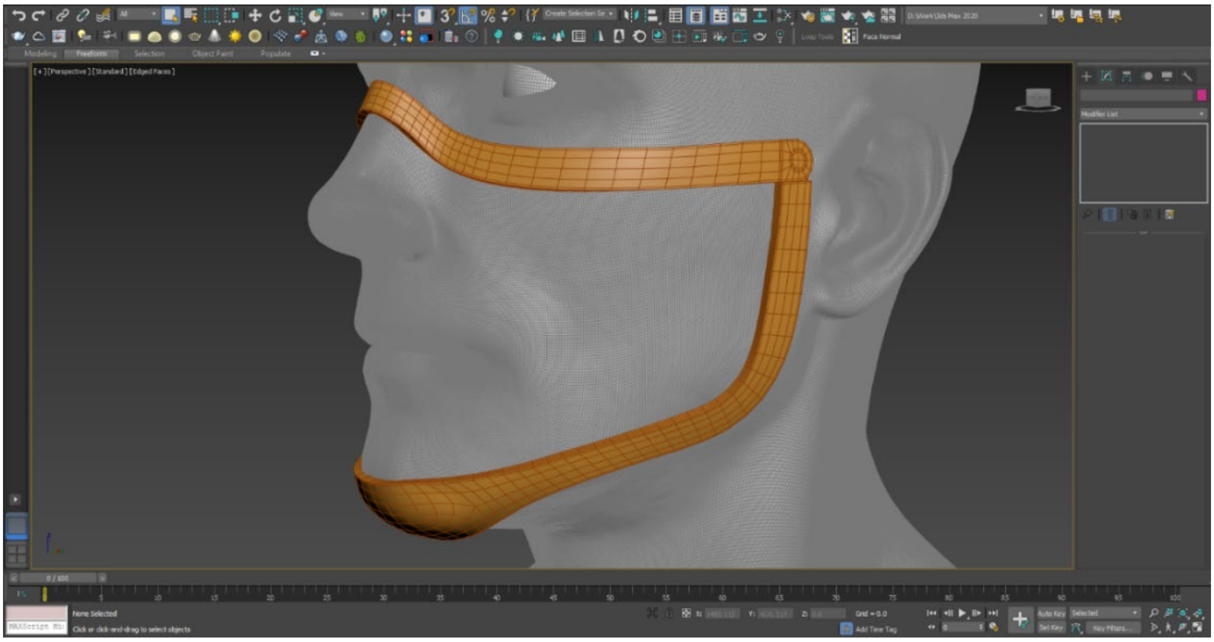


Fig. 6. Solid model of the mask wireframe in Autodesk 3Ds Max

At the fourth stage, we check the design of the mask for reliability. The structure of the mask frame consists of two main parts, which are interconnected by a swivel joint. This allows using the mask when changing facial expressions and the conversation of the user of the mask. The lower part fits snugly against the chin, and the upper part is fixed on the bridge of the nose.

Autodesk Fusion 360 can simulate loads on all mask parts and joints. This allows checking the reliability of the structure for mechanical loads and attachment to the face. We set the material for the supporting structure of the mask and check for external forces and possible movement when changing facial expressions during a conversation. After testing, it is possible to adjust the shape of the mask structure.

The 3D solid model of the mask wireframe in Autodesk Fusion 360 is shown in Fig. 7.

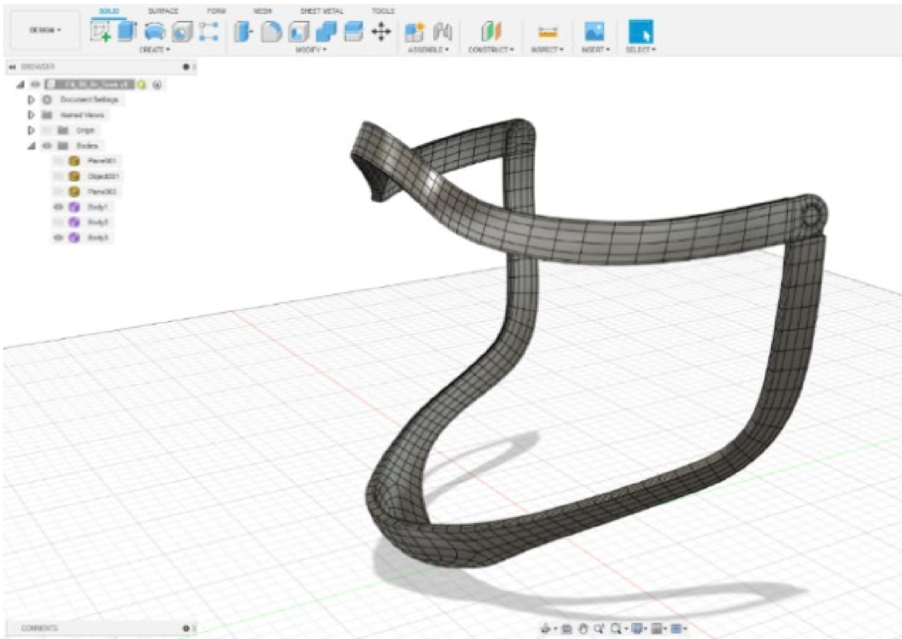
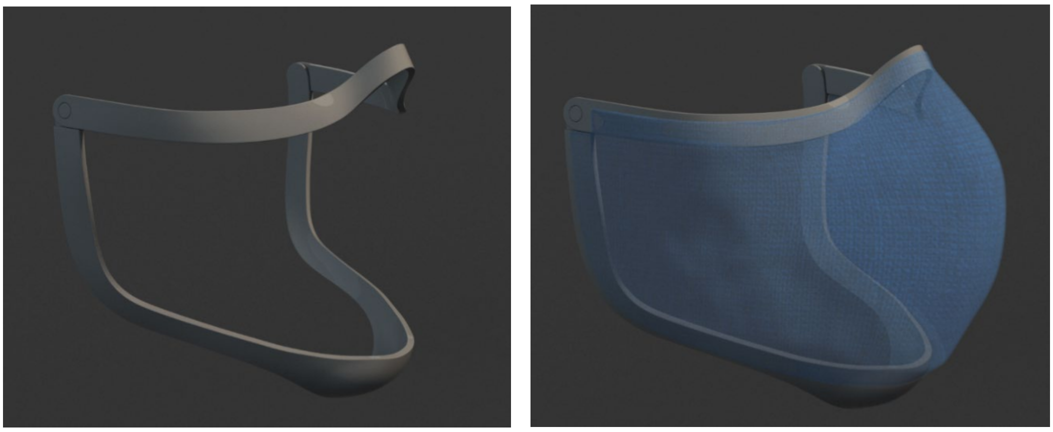


Fig. 7. 3D solid model of the mask wireframe in Autodesk Fusion 360

At the fifth stage, we determine the type of the filtering element and, in accordance with result, set the type of its attachment to the supporting structure. Let's consider the simplest option using a replaceable multi-layer filter element. Taking into account the shape of the mask's supporting structure it can be made in advance. The filter element is attached to the supporting structure with an adhesive layer. The sticky layer can be applied to the filter element and the supporting structure. If necessary, correction of the bearing structure of the mask is possible, taking into account the reliable fixation of the filter element.

After determining the filter element, we develop a technology for manufacturing the mask frame. We choose additive technology using a 3D printer as the main technology. In Autodesk Fusion 360, you can simulate the workflow of creating an object based on a 3D printer. Using cloud technologies, we load the parameters of the required 3D printer and simulate the manufacture of a mask frame. If difficulties arise during the simulation, the program prompts the necessary shape corrections or the addition of fasteners.

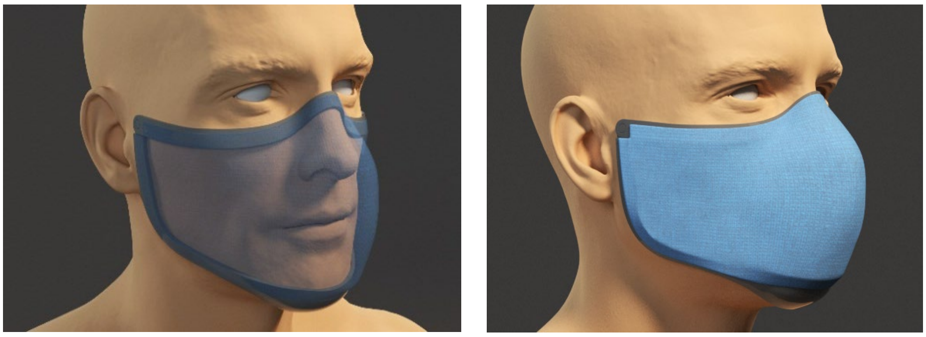
The final version of the mask frame and the finished mask after simulation of manufacturing on a 3D printer are shown in Fig. 8, *a*, *b*. The mask "dressed" on the face is shown with a transparent and opaque filter in Fig. 9.



a *b*

Fig. 8. Mask frame (*a*) and finished mask (*b*) after load simulation

After creating the mask, it was placed on the head model. It is precisely placed in the required place. The resulting image of a mask with a translucent and non-translucent filter is shown in Fig. 9.



a *b*

Fig. 9. Mask "dressed" on the face

Conclusions

The paper proposes an approach to the creation of a protective mask, taking into account the individual characteristics of a person's face. When designing the mask, the information model of the created object was used. The information model includes all sequential stages of mask creation. The general approach and the real version of creating a protective mask with a replaceable filter are considered in detail. To increase the reliability of attaching the mask to the face, it is possible to add ear-hooks like glasses. Using an information model to create a mask reduces design time, improves accuracy, and avoids errors in the generated model. The proposed method for designing a mask using an information model can be applied to other objects of this type. The development of the work will be the design of a reusable mask using options for different types of filters.

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Received May 07, 2021

Accepted June 21, 2021