Development of Smart and Powered Anti Infection Face Mask
Akıllı ve Güç Destekli Anti Enfeksiyon Yüz Maskesi Geliştirilmesi

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Abstract—**The COVID-19 virus, which emerged at the end of 2019 had affected the whole world and had different effects in many areas. One of these areas was respiratory protective equipment technologies. In normal, masks are products that are mostly used in environments where there is a factor such as gas, smoke, or dust that threatens to breathe. Due to the airborne transmission of the COVID-19 virus, masks were used in all areas of human interaction during the epidemic period. As the use of masks became widespread, there was feedback about the products and it was revealed that these products had deficiencies and aspects to be improved. In this study, the deficiencies of the mask products that came to light during the COVID-19 epidemic period and the aspects that can be improved were examined and a smart and powered respiratory protective half-face mask was developed that can be a solution to these problems. The mask produced has two electronic fans and can be controlled via the mobile application by Bluetooth connection. In this way, the user can supplement the filtered clean air into the mask when necessary. In addition, the air evacuated outside the mask is filtered and then given to the environment. As a result, the problems related to mask products that emerged during the COVID-19 epidemic were resolved with the developed mask.**

Keywords—COVID-19; mask; wearable technology; powered respiratory protective equipment

Özetçe—**2019 yılının sonunda ortaya çıkan ve tüm dünyayı etkisi altına alan COVID-19 virüsünün birçok alanda farklı etkileri olmuştur. Bu alanlardan biri solunumu koruyucu ekipman teknolojileri olmuştur. Normal şartlarda maskeler çoğunlukla solunumu tehdit eden gaz, duman veya toz gibi bir etkenin olduğu ortamlarda kullanılan ürünler olmuşlardır. COVID-19 virüsünün hava yoluyla bulaşması sebebi ile salgın dönemi içerisinde insan etkileşimin olduğu her alanda maskeler kullanılmıştır. Maske kullanımı yaygınlaştıkça insanlarda ürünlerle ile ilgili geri dönüşler olmuş ve bu ürünlerin eksiklikleri ve geliştirilecek yönleri olduğu ortaya çıkmıştır. Bu çalışmada COVID-19 salgını sürecinde gün yüzüne çıkan maske ürünlerinin eksikleri ve geliştirilebilecek yönleri incelenmiş ve bu sorunlara çözüm olabilecek akıllı ve güç destekli solunumu koruyucu yarım yüz maskesi geliştirilmiştir. Üretilmiş olan maske iki adet elektronik fana sahip olup, Bluetooth bağlantısı aracılığı ile mobil uygulama üzerinden kontrol edilebilir. Bu sayede kullanıcı gerekli durumlarda maske içerisine filtrelenmiş temiz hava takviyesi yapabilmektedir. Ayrıca maske dışarısına tahliye edilen hava da filtrelenerek ortama verilmektedir. Sonuç olarak COVID-19 salgını sürecinde ortaya çıkan maske ürünleri ile ilgili problemler geliştirilen maske ile çözüme kavuşturulmuştur.**

Anahtar Kelimeler—COVID-19; maske; giyilebilir teknoloji; güç destekli solunumu koruyucu ekipman

I. Introduction

The COVID-19 epidemic has affected many areas in the world such as health, society, economy, education, and industry; radical changes have occurred in these areas [1]. For example, in Turkey, in order to adapt the health system to the epidemic, new generation applications such as HES Code [2], contactless healthcare, and monitoring health transactions via E-Nabız [3] have been implemented. In order to prevent the virus, which spreads more rapidly and effectively in areas with high population density, measures such as curfews, vaccination card applications, and the use of masks in public environments have been implemented [4]. During the epidemic period, there have been changes in the economic system due to the supply-demand imbalance, deterioration of the supply chain, and increase in production costs [5]. Following these changes, technological innovations in cargo and courier services, shopping with crypto money, e-commerce, and virtual store applications have become much more common than in the pre-epidemic period [6]. The industry and business world were interrupted in the early stages of the epidemic, and applications such as remote working became widespread in order to prevent the increasing number of cases [7]. One of the areas where the epidemic has an impact is mask technologies. During the COVID-19 Outbreak, it has been seen that the use of masks is an easy-to-apply and high-protection measure to fight against the respiratory-borne virus [8]. For this reason, the use of masks has been made mandatory, especially in closed areas where population density is high during the epidemic. Normally, the areas where the use of masks is mandatory are mostly working environments where there are chemicals, smoke, or dust that are dangerous to breathe. Even though masks have started to be used in daily life in countries such as China and Korea with the increasing air pollution recently [9], the usage areas of mask products are generally environments where there are substances harmful to respiration.

Mask products available in the market are produced and used in accordance with the working conditions of that area for each area of use [10]. For example, surgical masks, which are used at the highest rate during the epidemic, are the products used in the hospital environment to prevent respiratory infection between healthcare professionals and patients. Masks that have exhalation valve features are used to protect people working in environments with small granular parts that may be harmful to breathing. The common areas of use of visors, which are another product frequently used during the epidemic period, are areas such as machining and metal welding, where particles may hit the human face during work. With the effect of the obligation to use masks during the COVID-19 epidemic, people have tended to use mask products that are used in different sectors for purposes other than their intended [11]. The fact that mask products, which are used and experienced by a small group in society under normal conditions, are being used by a very large mass has brought feedback about the problems encountered in mask products. Due to the production purposes of mask products and their use outside of their capacities caused problems such as; increasing virus contagion [12], decreasing the life comfort of people using masks [13], decreasing respiratory performance of people using masks [14], environmental pollution caused by masks [15].

Although masks are intended to protect against the virus, it has been observed that in some cases it increases the spread of the virus. An example of this is N95 masks with exhalation valves. For example, valved N95 masks are masks that can filter 0.3-micron particles with a 95

With the use of masks being mandatory during the epidemic and the use of mask products by too many people, much feedback has emerged about mask products. The common point of this feedback is that masks reduce people's comfort in life [13]. The change of shape in the limbs after long-term use of surgical masks [19], difficulty in breathing due to pressure loss caused by filters [20], and problems in the transmission of sound to the other side while communicating [21] are among the main reasons that reduce comfort. This decrease in people's comfort of life indirectly led to secondary problems such as reducing the work efficiency of employees.

It has been observed that most of the masks used during the epidemic period are disposable masks. With the increase in the use of disposable masks in the later stages of the epidemic, a huge waste problem has emerged. The chemical processes and energy consumption required for the recycling of masks are other dimensions of environmental pollution caused by disposable masks [15].

In this study, the main problems that emerged with the use of mask products much more intensively than normal conditions during the epidemic period were examined and a mask was developed that can provide solutions to these problems with today's technologies. The mask that was designed as a result of the study; is a smart device produced from biodegradable materials that filters the incoming and outgoing air using separate filters, directs the inhaled and exhaled air with the valve system to separate channels, provides filtered clean air into the mask with the support of an electronic fan and can be controlled via Bluetooth with the support of a smartphone application.

II. Materials & Methods

Considering the features of the mask, mechanical and electronic assembly elements that can provide specified features were investigated. Elements that the smart mask should have chosen; a soft plastic part that ensures the contact of the mask with the face in a leak-proof way, the main body that contains all the elements of the mask, cartridge filters that filter the particles in the air, electric fans that increase the amount of air passing through the filters and reaching the respiratory organs, a valve that regulates one-way airflow, a Bluetooth module that provides smartphone connection, a button that provides control on the mask, a battery that powers the mask, a battery charger and finally a microcontroller that can control all electronic components. In order to provide all these features and to manufacture a powered facemask; material and equipment selection, mechanical design, electronic design, software, production, and assembly processes were planned respectively.

A. Material and Equipment Selection

The material and equipment selection process was followed by taking into account the targeted features of the mask being developed. It was decided to use FDM (Fused Deposition Modeling) 3D printing devices, which is one of the additive manufacturing methods, for the production planned to be carried out in the laboratory environment. In this study, Ultimaker 2 Extended+ and Anycubic I3 Mega devices were used for 3D printing. For the assembly of electronic parts, assembly processes were carried out with a soldering iron and a hot air station.

After deciding on the devices and equipment to be used for production and assembly, the selection of mechanical and electronic consumables to be used in the mask was started. For the soft part in contact with the face TPU (Thermoplastic Polyurethane) and for the main body of the mask PLA (Polylactic Acid) material was preferred. The fact that TPU material has a flexible and soft structure, PLA material has a hard and durable structure, and that both materials can be produced by the 3D printing method were the main factors in the selection of these materials. For the production of cartridge filters, it was decided to use HEPA filter fabric, which can filter 99.95% of 0.3 μm particles in the air, and PLA material for the production of the hard parts of the cartridge.

It was decided to use an electronic fan to increase the amount of air passing through the filters and reaching the respiratory organs. The limitations determined by the American National Institute of Occupational Health and Safety (NIOSH) were taken into consideration in the selection of fans. According to NIOSH data, a sealed mask should have an air-blowing capacity of at least 115 LPM (Liter Per Minute)

[22]. Two FCN DFS150505000T blower fans with a total air blowing capacity of 140 LPM, operating with 5V and 0.5A DC current, were selected to provide the specified airflow. The volume occupied by the fans in the mask was also one of the important factors affecting the design of the mask and the selection of fans. Fans each have a volume of 55x55x5 mm^3 were preferred because they have a much lower volume than fans with similar air-blowing capacity.

A one-way exhalation valve system was needed in order to successfully achieve one-way air flow in the mask. After examining different valve systems, a flap-type valve system was used, which is already used in masks such as the 3M 7500 series.

For the mask to communicate with the smartphone and to do this with low power consumption, the HC-05 Bluetooth module was used. HC-05 consumes only 30 mA current thanks to its BLE (Bluetooth Low Energy) feature.

Two Power-Xtra 3.7V 2700 mAh lithium polymer batteries were used to power the electronic components of the mask and to make the mask work for long hours. In order to charge the batteries that are connected in parallel and have a total capacity of 5400 mAh, IP2312 USB Type-C fast charging module, which can provide 3A current, was used.

Control of all electronic components in the mask was provided by the Arduino Pro Mini microprocessor [23], [24]. Its small 33x18x1 mm size and low power consumption between 18-26 mA are the main factors in choosing the Pro Mini. A "Slider" type switch was used on the mask to turn the power on and off, and a "Push Button" type switch was used to provide fan speed controls. Finally, a 4-point headband was used to fix the main body of the mask on the human head in an ergonomic way.

B. Mechanical Design

Since the mask is a device worn on the human face, it has a limited volume and surface area that it can cover. A design that is large enough to close the eyes or restrict neck movements is not suitable for use. In addition, the volumes covered by mechanical elements such as filters, fans, and flaps on the mask are parameters that affect other design processes. For these reasons, the mask design was started with the mechanical design studies (Fig. 1).

The mechanical design studies were started by taking the scanned human head models as a reference. The scanned models used are the result of extensive work done by NIOHS. In the national study conducted in the USA, NIOHS scanned the heads of 3997 people and published a total of 5 different human head models, representing the head shapes of an average American citizen, using the scan data. Among the models shared by NIOHS, the "Large" human head model was used in the design studies carried out within the scope of this academic study.

After the determination of the human head model to be worked on, sketch drawing studies were carried out. Afterward, a decision was made on a model among the completed sketches, and CAD design works were started via Solidworks software. The first stage of the CAD design work was determined as designing a flexible part that could fit the human face model hermetically. In this process, open-source CAD models were examined first. Among the examined models, one of the models was found to both cover the facial features and be easily manufactured with additive manufacturing methods. This EVO II for 3D printing model [25] has been brought to the mask design with the changes and rearrangements made on it.

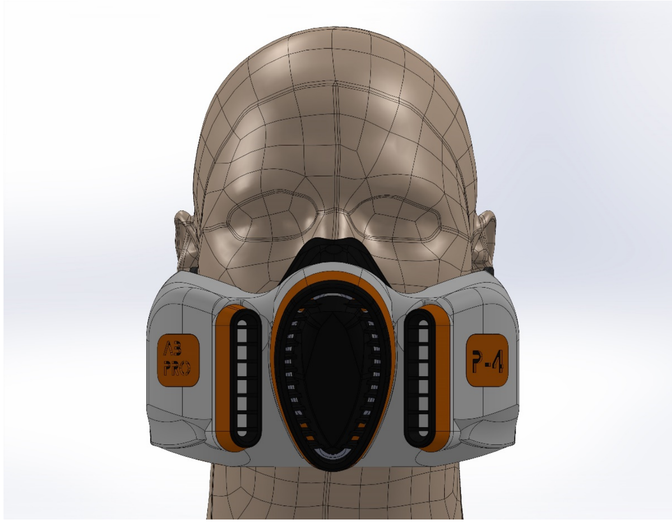

Figure 1: The mechanical and industrial design of the mask.

After the design of the face piece in contact with the human face was completed, the main body design was started. It was aimed that the main body design should have an ergonomic, aesthetic, durable, low-volume, and weighted structure that could contain all mechanical and electronic elements together. In order to design the main body to have a volume that can cover all electronic and mechanical elements; 3D drawings of the fan, electronic card, battery, etc. components were created first. The parts, whose drawings were completed, were placed in their desired positions in a 3D space, including the human head model.

The main body of the mask was formed to include the mechanical and electronic elements whose positions were determined. The main body was designed to consist of two main sections, the side sections, and the middle section. There are HEPA filter cartridges, fans, and electronic elements that filter the air entering the mask in the side sections. In the middle section, there is an exhalation valve system and a HEPA filter cartridge that filters the air coming from the mask. The zones must be accessible from the outside, as each main zone houses a filter cartridge and the cartridges must be replaceable. It is planned that the covers, designed with the magnetic assembly method, will provide the feature of being easily closed and opened. Air ducts opening to the middle section were designed so that the fans located on the sides of the main body can blow air to the respiratory organs.

After the body design was completed, the part was formed into a 4 mm thick shell to reduce the bulkiness. Weak areas in the shell body were strengthened using chambers. After the design of the main body parts such as covers, air ducts, and slots where electronic and mechanical elements are located completed, industrial design works were carried out to give the mask an aesthetic appearance. Instead of bland and regular lines, a smoother and circular design language was used in the mask. In addition, an unordinary design was achieved with the color combination consisting of 3 different colors. With the end of the industrial design work, the mechanical design of the mask was completed.

C. Electronic Design & Software

Material and equipment selection studies for the mask formed the basis of electronic design and software studies. Module and circuit element selection for targeted features is a critical starting point for electronic design [E]. Likewise, the choice of microcontroller among the selected circuit elements directly affects the software work. Material and equipment selection was made by considering these criteria. EasyEDA software was used for electronic design. All electronic elements to be used on the mask were designed and simulated on a single circuit diagram using the software. The circuit diagram designed via EasyEDA software is shown in Fig. 2.

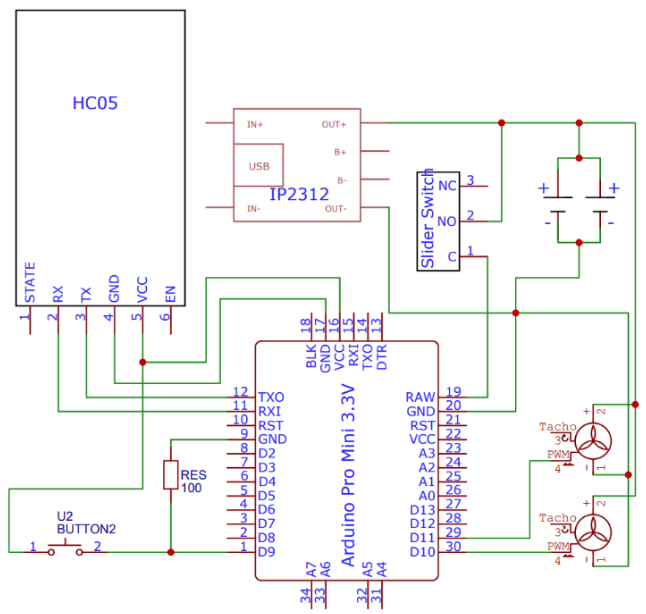

Figure 2: Diagram of electronic elements inside the mask.

Software studies were carried out to control the speed of the fans in the mask and to provide the communication of the mask with the smartphone application. It is planned to control the speed of the fans with two different methods: the "Push Button" switch on the mask and the smartphone application. With the and “HIGH”. PWM values corresponding to these speed settings were determined as “LOW=186”, “MED=200” and “HIGH=255”. To control the speed settings, software has been developed that will switch the fans to a higher level each time the "Push Button" is pressed and will turn the fans off when pressed in the highest "HIGH" state. The smartphone application shown in Figure 3 was developed via the MIT App Inventor software to control the fan speeds via a smartphone. Smart phone-mask Bluetooth connection can be provided with a single button through the application, which has a simple interface. The fan speed corresponding to the key pressed can be adjusted with the “LOW”, “MED” and “HIGH” keys on the interface (Fig. 3).

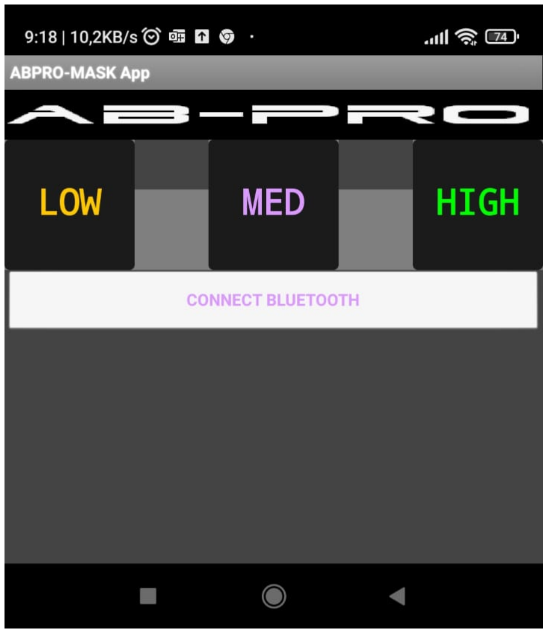

Figure 3: Android application developed for the fan speed control.

The circuit designed via EasyEDA software was set up using breadboard and jumper cables. The software developed with Arduino IDE was uploaded to the microcontroller in the built circuit, and the mobile application developed via MIT App Inventor was uploaded to a smartphone with the Android operating system. Afterward, electronic circuits and mobile application were tested, problems encountered were resolved and electronic design and software studies were completed.

D. Production & Assembly

After the mechanical and electronic design studies were completed, the production started. All mechanical parts designed via Solidworks software were sliced using Ultimaker Cura slicer software and made ready for 3D printing. Since the parts had mostly shell structure, the infill percentage was selected as 100% on the slicing software to ensure that the parts were more durable. During 3D printing, different color PLA filaments were used for each different part to achieve the color combination of the industrial design work. After the printed parts were visually checked and it was ensured that there was no deformation or deterioration, the assembly stage was started.

The assembly started with the application of super glue on the 3D printed parts produced for the main body hermetically. The magnets of the covers that allow the filters to be easily changed on the main body are positioned and adhered with superglue in such a way that the magnet poles on the body and the cover are opposite. After the parts printed for the main body were assembled by using superglue, the assembly of the electronic components was started. Electronic parts, whose locations were determined as a result of mechanical design studies, were fixed in their positions with super glue. With the circuit diagram prepared as a result of the electronic design studies, the electronic components were connected with cables and solder. After the assembly of the electronic and mechanical elements was completed, the straps of the 4-point headband were passed through 4 separate slots on the main body and the assembly process was completed. The fully assembled mask is shown in Fig. 4. In the assembly of the mask, the shrink-fit method was used to fix the replaceable cartridge filters and to increase the air tightness. Fig. 5 shows the assembly of the filter cartridge.

Figure 4: a) Completed assembly of the mask. b) Removable covers of the mask using the magnetic assembly method.

III. Results and Discussion

In this study, the problems that arise with the increase in the use of mask products during the epidemic period

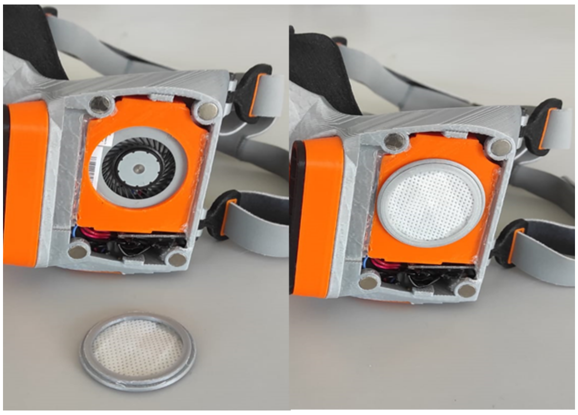

Figure 5: Replaceable cartridge filters, assembled with the shrink-fit method.

were examined and a smart, powered anti-infection mask was developed that could be a solution to these problems. The developed mask can provide the user with up to 140 liters of filtered clean air per minute. The speed of the electronic fans can be controlled in real-time via the "Push Button" switch on the mask and the smartphone application. The batteries in the mask with a total capacity of 5400 mAh allow the fans to operate at the highest speed for 5 hours. Thanks to the fast-charging module with USB Type-C input integrated into the mask, empty batteries can reach full charge in 2.5 hours. The weight of the assembled mask is 490 grams. The lightest power-assisted respiratory protective equipment available on the market CleanSpace Respirator [27] weighs 500 grams. When the mask that is designed and manufactured as a result of this study is compared with the CleanSpace Respirator, it is seen that it has almost the same weight. By improving the design in the future, the weight can be reduced and a more comfortable working environment can be provided to the user. The mask can be easily put on and taken off thanks to the Velcro fastenings of the 4-point headband. The developed face mask has easily replaceable filters in cartridge form. The smooth lines and color combination given to the mask during the industrial design works gave the smart device an aesthetic and innovative appearance.

The developed smart mask device participated in the TEKNOFEST 2021 Competition and was shown among the finalists. The developed mask product attracted great attention in the exhibition area. The smart mask has gained the attention and admiration of people from many sectors such as education, first aid, search and rescue, industry, and defense industry. For the mask to become a more advanced product, recommendations and feedback were received from experts. It has been seen here that the emerging problems of the mask products, which are the subject of this study, have been observed by people in different sectors; and the smart mask developed in this study is a product that can provide an alternative solution to these problems.

The mask device developed as the result of the study was presented as a prototype model. It is aimed to develop the materials, equipment, electronic parts, and production method used in the production of the prototype model with future studies. For example, the Bluetooth module on the mask is only used for speed control in the current prototype. In future studies, this module can be used with sensor technologies to read and send vital data to the phone application. Another example is the materials used for production and the production method. FDM printing technology and thermoplastic materials are used in the prototype product. Future studies, it is aimed to produce the mask with a plastic injection molding method and materials suitable for medical use. Future studies, it is aimed to support the mask with sensor technologies so that it can be controlled by feedback, using the electronic elements in the mask most effectively and efficiently with the support of artificial intelligence, and improving mechanical reinforcement and industrial design studies.

Author Contributions

M.T. Copoglu carried out the research, mechanical, electronic design, production, and assembly works of this study. H. Oflaz provided scientific and academic consultancy throughout the entire study and also acted as the executive of the project.

Acknowledgements

The smart mask designed and manufactured in the study had the opportunity to meet with users and receive feedback in TEKNOFEST 2021 Competition. We would like to thank, the T3 Foundation for organizing TEKNOFEST, TÜBİTAK for funding the project number "221M080" within the scope of "TÜBİTAK 1005 - National New Ideas and Products Research Support Program", and HGO MEDİKAL A.Ş. for providing technical and academic consultancy at all stages of the study.

The authors declare that they have no conflict of interest.

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