INTRODUCTION

The World Health Organization or WHO announced that the 2019 Coronavirus Disease had become a global pandemic on March 12, 2020 [1]. Covid-19 cases in Indonesia are increasing, as of August 27, 2021, 4.07 million positive cases of Covid-19 have been confirmed in Indonesia [2]. Covid-19 is a disease caused by the Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2). This disease can spread through small droplets from the nose or mouth of patients when coughing, sneezing, and breathing [3].

Health professionals who treat Covid-19 patients have a very high risk of contracting it because they often contact patients [4]. It was recorded that in August 2021 cases of death of health professionals due to Covid-19 had reached 1,967 cases of death [5]. Therefore, it is important for health professionals to wear Personal Protective Equipment (PPE) as protection when providing health services. PPE Level 3 is the highest level of PPE used when providing services to avoid droplets of Covid-19 patients. PPE level 3 consists of hazmat (hazardous materials suit), goggles, face shield, gloves, boots, and so on [4]. The use of level 3 PPE that completely covers the body can reduce the risk of transmission from patients to health professionals. But on the other hand, it also creates difficulties and inconveniences in using medical devices that do not support this situation, such as the use of a stethoscope [6][4].

The stethoscope, as an iconic medical device [7][8] is used to check the patient's health by listening to internal sounds or auscultation [9]. A stethoscope is very important for examining Covid-19 patients, especially those with severe symptoms such as acute respiratory failure [10]. Generally, these symptoms look like viral pneumonia or pneumonia due to infection [11][12]. Pneumonia has specific characteristics that are related to the radiological picture of Covid-19 patients. Auscultation using a stethoscope is an initial physical examination to diagnose pneumonia by listening for abnormal breath sounds [13].

In addition to pneumonia, heart disorders are often found in Covid-19 patients, such as myocardial injury, myocarditis, and acute coronary syndrome. Disorders of heart rhythm can also occur after treatment with QT-prolonging drugs [14].
disorders can lead to heart failure if not treated quickly and appropriately. The difference in heart rates and pulse rates is an early sign of heart failure that must be detected quickly. Monitoring the electrical activity of the heart is also necessary when examining patients with heart rhythm disorders.

The stethoscope commonly used today is the acoustic stethoscope which uses tubing to connect the diaphragm and earpieces [15]. Reference [6] said that acoustic stethoscopes are challenging to use when treating Covid-19 patients because there is no gap in level 3 PPE to insert a tubing. In terms of quality, the sound that can be heard through this acoustic stethoscope is also shallow [16]. Apart from the difference in human hearing sensitivity, some sounds transmitted by acoustic stethoscopes become inaudible, such as frequencies less than 50 Hz [17]. The transmission process reduces auscultation accuracy [18]. The shortcomings of acoustic stethoscopes raise the need for a stethoscope breakthrough that can be used by health professionals comfortably while still applying technical guidelines for health services during the Covid-19 period.

The solution so that the stethoscope can be easily used when wearing level 3 PPE is to use an electric stethoscope connected to a headphone. However, this type of stethoscope is still difficult to use because it still uses a cable for the headphone [6]. The connector between the stethoscope and the headphone is also vulnerable to damage, so it still causes problems. This solution also does not meet the needs of health professionals for monitoring the patient's electrical activity and heart rate. Another existing solution is a digital stethoscope that connects to a smartphone and earbud wirelessly. However, the use of an earbud for a long time can cause discomfort and interfere with hearing function [19]. This digital stethoscope must also be connected to the application on the device so that its use becomes less practical. Procurement of an apparatus for each stethoscope is also not economical, while personal devices can increase the risk of virus contamination [20].

This activity aims to create a stethoscope that can answer the challenges of examining patients in accordance with technical guidelines for health services during the Covid-19 period. This stethoscope has three main objectives, namely, providing convenience and comfort when used according to the needs of health professionals. The importance of auscultation proves that health professionals need a stethoscope that can produce good sound quality. Another need is a stethoscope that can be used even when health professionals wear level 3 PPE and the comfort of health professionals. Health professionals can use this digital stethoscope comfortably because there is no need to unplug PPE and without fear of being contaminated with viruses when examining patients. Another advantage of this tool is that it can display electrical activity and heart rate per minute and record auscultation sound so that it is easier to detect organ disorders according to the needs of monitoring the heart's electrical activity in patients. In addition, the recording feature is also helpful for digitally recording patient medical records and advances in science and technology. This tool is also equipped with a screen and does not require the help of a device so that it is more practical, economical and reduces the risk of virus contamination.

**METHOD**

This digital stethoscope is made with steps starting from problem identification, determination of specification requirements, design and implementation of tools, testing, analysis to repair. These steps are illustrated by Figure 1.

![Figure 1. Flowchart of the Implementation Stage](https://example.com)

**Problem Identification and Determination of Specifications**

Problem identification is made by directly discussing with two doctors who treat Covid-19 patients and through literature studies on existing solutions. This discussion is useful for knowing the conditions and problems faced by health professionals regarding the use of stethoscopes during the Covid-19 pandemic. The stethoscopes commonly used by health professionals are the acoustic stethoscope in Figure 2(a) and the electric stethoscope connected to the headphone in Figure 2(b).

![Figure 2. (a) Acoustic Stethoscope (b) Stethoscope with Headphone](https://example.com)

The results of problem identification are taken into consideration in formulating a solution plan for each problem. Each solution plan has specifications to meet the needs, convenience, and comfort of using a stethoscope during the Covid-19 pandemic.

**System Design and Implementation**

The schematic design of the digital stethoscope system is described in Figure 3. Input in the form of auscultation sounds is detected using a condenser mic connected to the tubing. The detected sound in an analog signal is forwarded to the pre-amp...
circuit, first amplifier, filter, and second amplifier. The processed signal is forwarded to four types of output. The first output of a stethoscope is the auscultatory sound produced by a wired audio device. The second output is the Bluetooth-based wireless audio device. The third output is a screen display that provides information on the electrical activity of the heart and the number of heartbeats per minute. The final output is auscultation sound recording stored in digital memory and can be listened to again.

Guidelines for health services during the Covid-19 period. A discussion was held with two doctors regarding using an acoustic stethoscope and an electric stethoscope with headphones. The problems faced by health professionals who are divided based on their objectives can be seen in Table 1. Acoustic stethoscopes have not met any of the issues required by health professionals to examine patients. An electric stethoscope with headphones has good sound quality, can be used with level 3 PPE and has a low risk of virus contamination. However, the drawbacks of the two stethoscopes are the subjectivity of the sound being heard and the convenience based on the type of output.

Table 1. Problems with Acoustic and Electric Stethoscopes

| Objectives | Issue | Acoustic | Electric |
|------------|-------|----------|----------|
| Needs      | Sound quality | Available to be used when PPE level 3 | ✓ | ✓ |
|            | Subjectivity | Low risk of contamination | x | x |
| Convenience| Lots choice communication | | | |
| Comfort    | Risk virus contamination | | | |

Based on the needs of health professionals for the shortcomings of acoustic and electric stethoscopes, an objective diagram for the design of the new stethoscope is formulated, as illustrated in Figure 4. Each issue in the stethoscope has a solution to solve the problem. The main advantage of this digital stethoscope is the availability of both wired and wireless communication options. In addition, visualization of the electrical activity of the heart and the ability to record sound are also features that make it easier for health professionals. This stethoscope can be used without having to remove level 3 PPE when examining patients, so the risk of virus contamination is low. It aims to increase the comfort of health professionals.

RESULTS AND DISCUSSION

Stethoscope Specification

The digital stethoscope was created by considering three objectives: the needs, convenience, and comfort of health professionals when examining patients according to technical

Testing and Analysis

This digital stethoscope has obtained an ethical license with No. 555/UN.16.2/KEP-FK/2021 from the Research Ethics Commission, Faculty of Medicine, Universitas Andalas. This digital stethoscope is tested for function and performance. Functional tests of this stethoscope include wired and wireless communication function tests, sound recording feature function tests and visualization function tests of the heart's electrical activity and the number of heartbeats per minute. Performance tests against digital stethoscope specifications include signal amplifier circuit tests, filter circuits, wireless operating range and energy consumption.

The user satisfaction test was carried out on seven health professionals who have experience in handling Covid-19 patients. This user satisfaction test is related to three predetermined objectives: the need for auscultation examinations, convenience, and comfort of health professionals when using them. Health professionals are asked to use a stethoscope made to listen for heart sounds, breath sounds, bowel sounds, and blood vessel sounds at auscultation points. In addition, health professionals are also testing the visualization feature and recording the heart's electrical activity. After using this stethoscope, health professionals are asked to provide an assessment of three objectives.

Figure 3. Schematic of the Tool

![Figure 3. Schematic of the Tool](https://doi.org/10.25077/ajeet.v1i2.14)
supporting variables. These specifications are available in Table 2.

**Table 2. Specifications of Digital Stethoscope**

| Category       | Variable            | Specification                   | Device          |
|----------------|---------------------|---------------------------------|-----------------|
| Communication  | Cable               | Mono                            |                 |
|                | Wireless            | Bluetooth 4.2                   |                 |
|                | Wireless operating  | Maksimal 8 m                    |                 |
|                | distance            |                                 |                 |
| Body           | Dimensions          | 76,62 x 50 x 28,69 mm           |                 |
|                | Mass                | 240 g                           |                 |
|                | Material            | PLA+                            |                 |
| Screen display | Type                | UG-2864HLBEG01                  |                 |
|                | Size                | 21,74 x 10,86 mm                |                 |
|                | Resolution          | 128 x 64 pixel                  |                 |
| Microcontroller| Type                | ATmega 328P                     |                 |
|                | Clock speed         | 16 MHz                          |                 |
|                | Flash memory        | 32 KB                           |                 |
|                | EEPROM              | 512 Bytes/1 KB                  |                 |
| Amplifier      | Type                | TDA 2822                        |                 |
|                | Magnitude           | 100 times                       |                 |
| Filter         | Type                | Band pass filter                |                 |
|                | Cut off             | 20 – 700 Hz                     |                 |
| Battery        | Type                | Lipo E-model                    |                 |
|                | Capacity            | 2200 mA                         |                 |
|                | Voltage             | 7.4 Volt                        |                 |
| Storage        | Type                | MicroSD card                    |                 |
| Operational voltage |                  | 5 Volt                          |                 |
| Energy consumption |                | 4.4 Watt                        |                 |

**Result of Design and Implementation**

The digital stethoscope has a four-part electrical system consisting of a pre-amp, a first amplifier, a filter, and a second amplifier. The pre-amp serves to convert a weak sound signal into a strong enough signal to be further processed into the first amplifier circuit. The first amplifier circuit serves to amplify the sound signal and is then filtered on the filter circuit. The filtered signal is then amplified again so that the sound signal is clearer. The output of the design is analyzed to see that the system response has succeeded in filtering and amplifying according to the design. The graph of the system response signal can be seen in Figure 5.

It can be seen in Figure 5 that the heart rate and breath signals have been successfully expelled clearly. After designing the electrical system of the stethoscope, the mechanical design and layout of the components used in the stethoscope are carried out. There are several parts and components used in a stethoscope as shown in Figure 6.

**Function Test**

Functional testing includes four aspects as shown in Table 3. Functional testing of wired and wireless communication features has been carried out by listening to the auscultated sound using various connected audio devices. Wired communication is tested by listening to the sound through the speaker and headphones. Meanwhile, the wireless communication test was carried out through an earbud, headphones, and a Bluetooth-based loudspeaker. The result of this test is that the auscultation sound can be heard through audio devices, both wired and wireless.

**Figure 6. Parts of a Digital Stethoscope**

![Figure 6. Parts of a Digital Stethoscope](image)

**Table 3. Functional Test Results of Digital Stethoscope**

| No | Aspect                           | Status      |
|----|----------------------------------|-------------|
| 1  | wired communication features     | Functionate |
| 2  | wireless communication features  | Functionate |
| 3  | Activity and heart rate visualization features | Functionate |
| 4  | Auscultation voice recorder features | Functionate |

Testing of the electrical activity display features of the heart and the number of heart beats per minute is also carried out by auscultation and viewing the visualization results on the stethoscope screen as shown in Figure 7. The X axis shows the time in seconds and the Y axis shows the amplitude. The cardiac electrical activity graph may appear on the display screen for a maximum of 10 seconds and will shift continuously. The number of heart beats per minute is calculated for 10 seconds which results will be multiplied by 6 to produce the number of heart beats for 1 minute.
The sound recording feature has been tested by auscultating, recording, and listening again. The recorded sounds are heart sounds, breath sounds, bowel sounds, and blood vessel sounds. After being recorded, the auscultation sounds are stored on a microSD, then listened to again using loudspeakers and a laptop. The recorded sound that is heard through loudspeakers and laptops can already be heard and is the same as the auscultatory sound that is heard live.

**Performance Testing**

**Signal Amplifier Circuit Test**

The function of the amplifier circuit is to amplify the sound signal. The amplifier circuit on a digital stethoscope can be seen in Figure 8. The first amplifier circuit and the second amplifier use the TDA 2822M Op-Amp IC. The magnitude of the amplifier circuit gain on a digital stethoscope is 100 times the gain according to equation (1).

\[
\text{Gain} = \frac{V_{out}}{V_{in}}
\]  

(1)

**Filter Circuit Test**

The function of the filter circuit is to pass signals with a specific frequency range and eliminate signals outside that frequency. The filter used is a type of bandpass filter, namely a filter that combines a high pass filter and low pass filter in one circuit. The high filter will cut the frequency value below its frequency point, while the low filter will cut it above the limit point. The limit value of the bandpass filter is obtained by analyzing the sound signal using the Fast Fourier Transform (FFT) method. FFT is an algorithm to convert a signal in the time domain into a frequency domain to separate the constituent frequencies in the input signal. This domain changes to get the frequency of heartbeat, breath, and noise. A filter with a frequency range of 20 – 700 Hz was designed using a bandpass filter based on the analysis results. The bandpass filter circuit has been able to work correctly according to the cutting limit value. Figure 9(a) shows the graphic form of the heart rate sound frequency before filtering and Figure 9(b) graph after filtering.

Breath sound analysis also uses the same method to obtain a frequency graph of the breath sound signal before filtering in Figure 10(a) and after filtering in Figure 10(b).
The filter circuit used in this digital stethoscope can be seen in Figure 11. The filter used is a bandpass filter using a TDA 2822M IC.

**Wireless Operating Distance Test**

This digital stethoscope can operate wirelessly in both open and closed spaces. Distance experiments have been carried out to test the operating distance using a stethoscope. The experimental results can be seen in Table 4. Based on the experimental results, it can be concluded that this digital stethoscope can be used wirelessly in both open and closed spaces.

**Energy Consumption Test**

The battery used in this digital stethoscope has a capacity of 2200 mAh. Energy consumption testing has been carried out to see the length of time the battery used in the digital stethoscope has been used. The usage time with wired communication can last up to 3 hours. Meanwhile, with Bluetooth-based wireless communication can last for 2.5 hours.

**User Satisfaction Test**

Testing the satisfaction of digital stethoscope users has been carried out with seven health professionals by performing auscultation, as shown in Figure 12. Health professionals, as users of this stethoscope, test the sound quality and features. After conducting the testing, health professionals were asked to assess the system based on three pre-determined objectives, namely needs, convenience, and comfort. The assessment is given with a scale range of 1 – 5. A value of 1 means that health professionals strongly disagree with the statement issued. A value of 5 means that health professionals strongly agree with the information given.
device also needs to be done to provide confidence to increase the stethoscope user's comfort.

CONCLUSIONS

The digital stethoscope is made based on three objectives that have been set as a solution to the problems faced by health professionals when examining patients according to technical guidelines for health services during the Covid-19 period. The objective is to meet the needs of health professionals, provide convenience and comfort when using. This digital stethoscope has both wired and wireless communication options that can connect to various audio devices. Another advantage of this stethoscope is that it can display electrical activity and heart rate per minute and can record auscultatory sounds. The recording results can be listened to according to the needs of health professionals. User satisfaction tests have been carried out on seven health professionals who also provide an assessment of the stethoscope that has been made. The assessment is given based on three objectives, namely needs, convenience, and comfort. The average rating is 4.69, which means that health professionals are very satisfied with the digital stethoscope. So it can be concluded that this digital stethoscope has been able to answer the needs of health professionals when conducting patient examinations according to technical guidelines for health services during the Covid-19 period. The auscultation sound output quality, both wired and wireless, can be heard clearly. The visualization and recording features are proven to help the work of health professionals. Health professionals considered that this digital stethoscope was easy and comfortable to use even though they were wearing level 3 PPE and could reduce virus contamination. This digital stethoscope is the right solution and in accordance with the needs and comfort of health professionals during the Covid-19 period.

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