Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 6, December 2023, pp. 3826~3836
ISSN: 2302-9285, DOI: 10.11591/eei.v12i6.5369

Text-to-speech on health monitoring bracelet for the visually impaired

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Article Info

Article history:

Received Nov 29, 2022
Revised May 25, 2023
Accepted Jun 5, 2023

Keywords:

Confusion matrix
Finite state automata
Health monitoring bracelet
Text-to-speech
Visually impaired aids

ABSTRACT

Text-to-speech (TTS) is a technology that converts text into sound using a phonetization system and is especially useful to be applied to blind aids who need information in the form of sound because of their limitations. To help the visually impaired know their health conditions where the visually impaired feel limited to going out during the pandemic. For this reason, it is necessary to make an aid that can read text-based data such as body temperature, heart rate per minute, and oxygen levels into a voice that can be heard by the blind, the method used in this study is finite state automata (FSA) which is used to split Indonesian words into words according to its syllable patterns and facilitate the pronunciation process which is included in the blind aids so that it is expected to help the visually impaired to be able to find out their health condition. In this study, the test was carried out using the confusion matrix method and the results obtained were 100% accurate, 99.71% accuracy of temperature sensor, 98% accuracy of heart rate, and 95% accuracy of oxygen saturation.

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1. INTRODUCTION

The development of knowledge and technology is making human work relatively easier because the technology created comes from the background of problems and anxiety that arise from the users themselves. Computer science and engineering that exists today have provided many benefits that can be applied in our lives, one of which we can see is in the field of automata theory, one of the largest areas related to the efficiency of an algorithm in solving problems in computational models. In recent years, many researchers have created and developed applications to help people who have visual impairments when they want to communicate with other people, one of which is technology from text-to-speech (TTS). The technology is converting text into sound using a phonetization system, that is phonemes that are arranged to form an utterance [1], the ability today has been quite good in converting text into sound [2]. The purpose of this technology is to make computers able to communicate and interact with everyday spoken language. The use of TTS today has been widely practiced by researchers, such as to recognize Vietnamese directly [3] or through a voice Bot [4], recognizing Japanese and English [1], the use of this TTS can also be used to conduct interviews [5], used in agriculture [6], and also helpful for people with aphasia [7]. In the configuration process, the words are split into syllables using Indonesian language rules with the aim that the resulting sound can be heard in the Indonesian language.

Researchers have done a lot of research that makes the visually impaired the object of their research, but most research done is more on walking aids for the blind using computer vision [8], [9], GPS [10], [11], and ultrasonic [12], [13]. However, there is only some research that discusses how the health condition of a blind person can be conveyed from text data into voice to blind people. This is considered very useful, as evidenced by research conducted that people with disabilities in reading are greatly helped by the presence of TTS applications [14].

Many methods are widely used for text processing, the one that is widely used is the finite state automata (FSA) method. Researchers have used this method to detect syllables in Indonesian language [15] to read the prefix of a word [16], read and translate Indonesian language to the Madurese language [17], and Latin to Sundanese [18]. The method is not only used to help translate text but can also be used to make predictions on time series data [19], verification tests [20], reading document similarity [21], and can even help to secure IP [22].

It is proven that this method has sufficient accuracy with a value of more than 80% [17], [18], [23], however, it still has limitations where it only processes text but not many convert it into speech, and the data used does not yet use health data, such as body temperature, heart rate, and oxygen levels. Some additional time information in the form of date, month, year, hour, and minute are also not added there. This will certainly be very useful if applied to a tool that is used by blind people to facilitate their accessibility in knowing their health condition. The rest of this paper is structured as: the literature review, which outlines the idea behind the study approach research strategy, is presented in section 2, section 3 presents and discusses the experiment's results, and in section 4 conclusions and work-related suggestions round up the section.

2. METHOD

2.1. Text-to-speech

A TTS or commonly called TTS synthesis is a computer-based system that can read text aloud automatically, whether the text is introduced by a computer input stream or a scanned input that is sent to optical character recognition (OCR) machine. Speech synthesizers can be implemented by both hardware and software and have made very rapid improvements over the decades and many high-quality TTS systems are now available for commercial use. Speech which is often based on natural speech sequences i.e., units taken from natural speech and put together to form words or sentences of simultaneous speech synthesis, the latter has become very popular in recent years due to its increased sensitivity to the context of the unit over its simpler predecessors. Rhythm is an important factor in making speech synthesized from the TTS system to be more natural and understandable, the prosodic structure provides important information to produce a prosodic generation model that is the effect in the synthesized speech. Many TTS systems were developed based on the principle of corpus-based speech synthesis due to the natural sound output, high quality, and very popular.

2.2. Finite state automata

As an abstract mathematical concept that describes the behavior of a logical machine that explains the workings of a physical machine, a program, an algorithm, or a problem-solving conception. In the context of language theory, the FSA engine can be applied to recognize a string that comes from a regular language that is generated from regular grammar. Thus, there is a reciprocal relationship between a regular language and FSA, that is, if it is owned by a regular language, a language can be constructed by FSA machine, then if it is owned by an FSA, a language will be derived and can be recognized by the machine.

The finite state machine can be a machine that has no output. A finite state machine that does not issue this output is known as a FSA [24]. In FSA the machine is initially in state S0 and receives a series of inputs which can change it to the next states. In FSA, there is also a certain set of states known as the final state. Changes from one state to the next follow certain rules that are formulated as a transition function.

FSA is an automatic machine of regular language. An FSA has a finite number of states and can move from one state to another [25]. This state change is represented by a transition function. The FSA has no storage space, so the ability to 'remember' is limited, it can only remember the most recent state. Examples of FSAs include elevators, text editors, lexical analysis, network communication protocols, and parity checks. Formally the FSA can be defined as TUPLE-5: a collection of five sets, or annotated as:

$$FSA\ is\ M = S, \Sigma, \delta, S0, and\ F$$

Where S is a finite set of states, $\boldsymbol{\Sigma}$ is a finite set of symbols on the machine, and $\boldsymbol{\delta}$=Q×$\boldsymbol{\Sigma}$ is a transition function that governs the movement of the machine. Among them is a function that takes states and an input alphabet as arguments and returns a state. S0 is the initial state and F is the set of a final state.

The behavior of FSA is expressed in the form of a transition table or the form of a transition diagram. Table 1 shows the example of syllable breaking from FSA itself. The transition function in the transition table is shown in Table 1, where from the transition table can be described the FSA transition diagram in Figure 1.

Table 1. Transition

State	δ Input 0	1
S0	S0	S0
S1	S1	S1
S2	S2	S2
S3	S3	S3

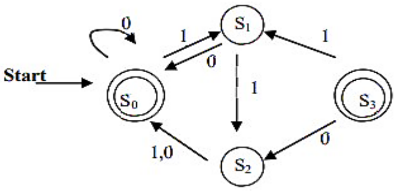

Figure 1. Example of a transition diagram

2.3. Research framework

The framework of thought in the research is divided into four parts: the first is data input, the second part is the process, the third is the output produced, and the last is the measurement. For the first, there are five data inputs: first the date and time data, heart rate, temperature data, oxygen saturation data which will then be processed by the FSA method, and next there is voice recording data that will be used after the finite state process automata are translated into sound. The third part is the output generated in the form of voice date and time, as well as the sound of heart rate, temperature, and oxygen saturation data. The last part is the testing section where testing is carried out using a confusion matrix to find out how accurate the FSA method is in recognizing and processing input. It is necessary to know the data obtained can come from sensor input stored in the database. Details of the research framework can be seen in Figure 2.

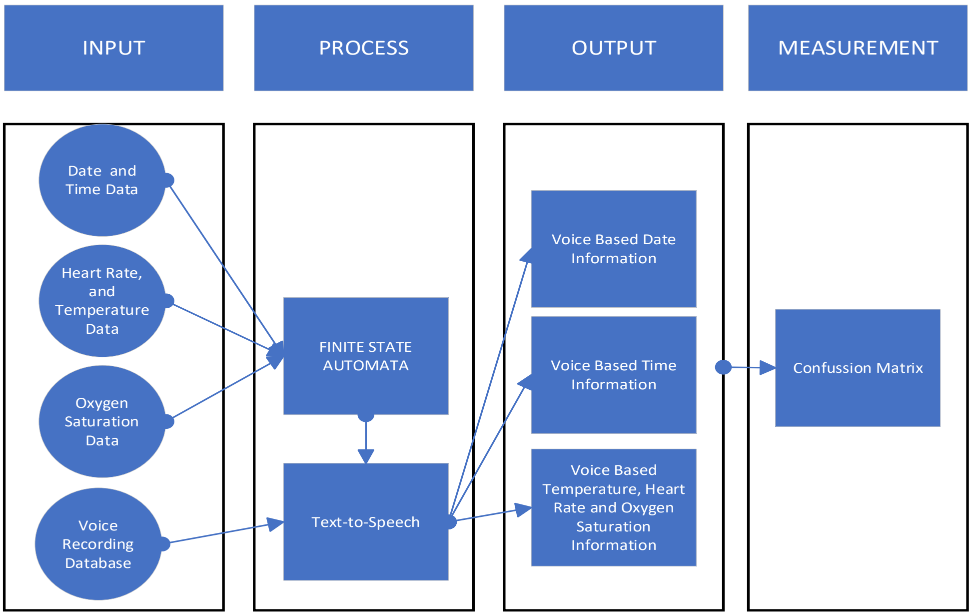

Figure 2. Research framework

2.4. Application of finite state automata

The FSA method is used to separate the words that are inputted and will be sent to TTS to be processed and output with sound results. Figure 3 shows the FSA method consists of four stages that need to be known before processing with FSA. Table 2 shows the text normalization step, in this step, every sentence text containing numbers, currency units, symbols, time, date, temperature, units, and abbreviations will be carried out in the text normalization process first.

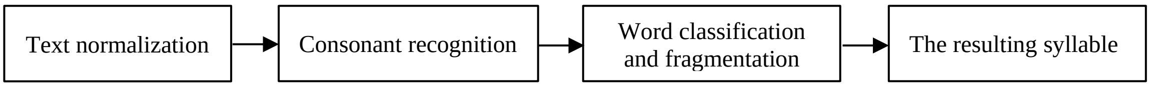

Figure 3. FSA stage

Table 2. Normalization

Text	Normalization result
0	*Nol*
1	*Satu*
2	*Dua*
3	*Tiga*
4	*Empat*
5	*Lima*
6	*Enam*
7	*Tujuh*
8	*Delapan*
9	*Sembilan*
10	*Sepuluh*
N>19 & <100	*Puluh*
11	*Sebelas*
N>99 & <1000	*Ratus*
100	*Seratus*
N>999 & <10000	*Ribu*
1,000	*Seribu*
°C	*Derajat celsius*
%	*Persen*

Consonant recognition, the next step performs the process to recognize letters after there is text input given from the tool. Besides letter recognition, there will also be an introduction to space punctuation marks. The letters B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, W, X, Y, and Z will be recognized as "K" or consonant. The letters A, I, U, E, and O will be recognized as "V" or a vowel. As the letters N, Y, and G will be recognized as the letter itself, those are: N as "N", Y as "Y", and "G" as "G". This arrangement will later aim to facilitate the classification of syllables if later in the reading of the text there are consecutive consonants presents.

Word classification and fragmentation, in this step, perform the classification and fragmentation of words described in the form of a transition diagram designed in three levels. At the first level that is recognized is the pattern: V, K, or KV. The results of the first level itself will be a continuation to the next level of FSA. Next is the level of the FSA transition diagram process, which is the second level which will recognize syllables with the pattern V, VK, VKK, KV, KVK, KKV, KKVK, KKKV, KKKVK for all consonants other than n, k, and s. Then, at the next level, the third level, it was explained that the syllable pattern of VKK, KVKK, KKVKK could not be recognized at the previous level. Therefore, the third-tier FSA can recognize these syllables.

The process of three transition diagrams above explains how the process of producing twelve-syllable/phoneme classifications from words that have been cut off according to Indonesian sentences. The goal is to recognize syllables in Indonesian sentences, by recognizing syllables in spoken language, it can be implemented into TTS. Figure 4 shows the design of the device from the research. There are two sensors used in this device, i.e.: i) pulse oximeter max 30100 sensors used to measure oxygen levels and heart rate and ii) DS1B20 sensor to detect temperature. The input obtained from the sensors will be processed using the FSA that is already embedded in the Raspberry. The FSA will be triggered when the button is pressed. The device also has a microSD which is used to store sound snippet data.

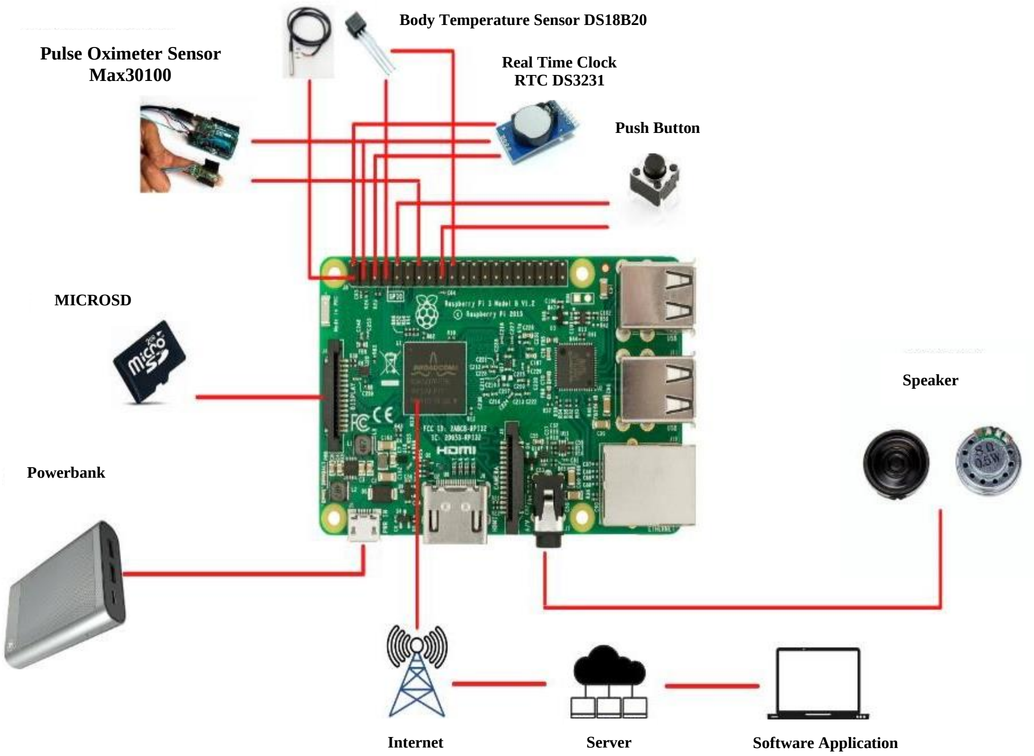

Figure 4. Tool design

Figure 5 explains the speech formation block diagram, after the button is pressed and the sensors have successfully read the body data for approximately 1 minute, the data will be processed using the FSA, and the data read will be normalized into text sequentially. Then, the FSA stage is executed, the sound file that represents the text is searched on the media storage in the microSD, and the sound will be issued through the speaker.

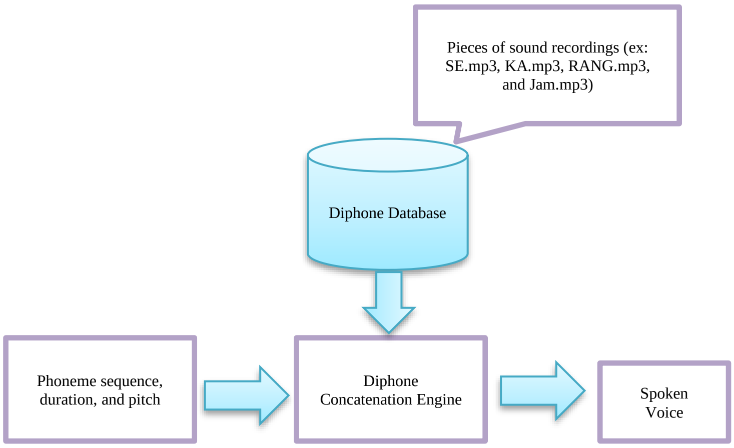

Figure 5. Speech formation block diagram

For the pronunciation to be pronounced all the words or sentences that have been compiled, there is a diphone database in which there is all the diphone data as in Figure 5. After that, through the diphone concatenation engine or processing unit, it will receive input in the form of a sequence of phonemes that will be pronounced along with the duration of pronunciation, pitch, or frequency. Then the smoothing of the connection between the diphones will be carried out, manipulating the duration of pronunciation, and pitch.

3. RESULTS AND DISCUSSION

3.1. FSA results

The results of the FSA in this study are divided into three parts: the first part produces the sound of the date, the second produces the sound of time, and the third produces the sound of temperature, oxygen saturation, and heart rate.

3.1.1. Date voice

Please note that the FSA works as follows:

$$FSA\ is\ M = (S, \Sigma, \delta, S0, and\ F)$$

where:
S: {S0, S1, S2, S3, S4, S5}
Σ: {blank/space, KV, V, KVK, KVKK}
δ**:** (S0, blank/space)=S1, (S0, KV)=S2, (S0, V)=S3, (S0, KVK)=S4, (S4, K)=S5
S0: initial state
F: {S0, S5}

The sounds that are processed in Figure 6, an example of the output that will come out is "*HARI INI TANGGAL TIGA BULAN AGUSTUS TAHUN DUA RIBU DUA PULUH SATU*". This sentence has been normalized in the form of numbers according to the previous step. If the word fragments described in the above process are described in "*HA-RI*", "*I-NI*", "*DATE-GAL*", "*TI-GA*", "*BU-LAN*", "*A-GUS-TUS*", "*TA-HUN*", "*DU-A*", "*RI-BU*", "*DU-A*", "*PU-LUH*", "*SA-TU*", in which each word will be separated according to the Indonesian language rules in the previous step.

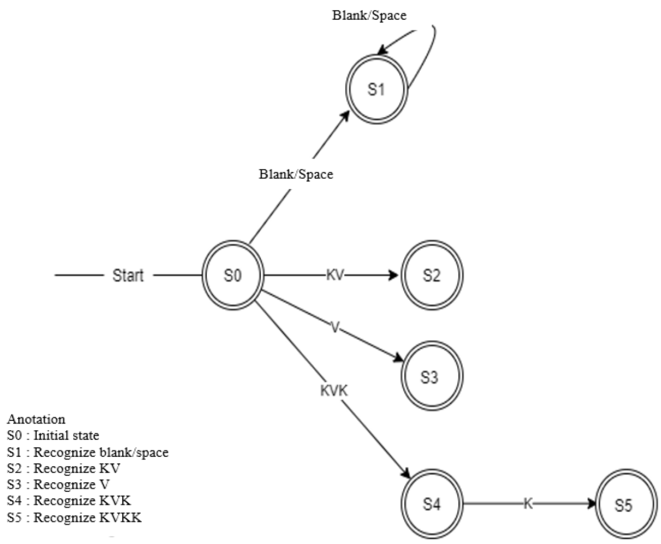

Figure 6. Date FSA transition diagram

3.1.2. Time voice

In addition to the application on date data, the next one is applied to time data, known:
S: {S0, S1, S2, S3, S4, S5}
Σ: {space/blank, KV, KVK, KVKK, V}
δ: (S0, blank/space)=S1, (S0, KV)=S2, (S0, KVK)=S3, (S3, K)=S4, (S0, V)=S5
S0: initial state
F: {S0, S5}

The sounds that are processed in Figure 7, an example of the output that will come out is "*SEKARANG JAM DUA BELAS NOL NOL*". This sentence has been normalized in the form of numbers according to the previous step. If the decapitation is described in the above process, "*SE-KARANG*", "*JAM*", "*DU-A*", "*BE-LAS*", "*NOL*", "*NOL*". Each word will be separated according to the Indonesian language rules in the previous step.

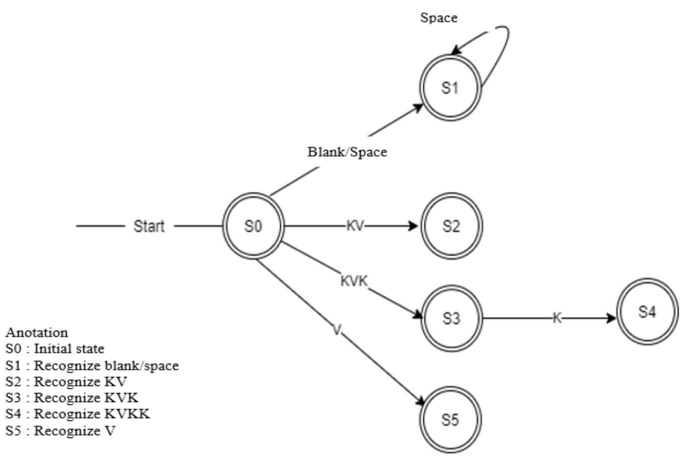

Figure 7. Time FSA transition diagram

3.1.3. Health data voice

Next step FSA applied to health data, known:
S: {S0, IS1, S2, S3, S4, S5, S6,}
Σ: {space/blank, KV, VK, V, KVK, KVKK}
δ: (S0, blank/space)=S1, (S0, KV)=S2, (S0, KVK)=S3, (S3, V)=S4, (S4, K)=S5, (S3, K)=S6
S0: initial state
F: {S0, S6}

The sound that is processed in Figure 8, an example of the output that will come out is *"SUHU BADAN TIGA PULUH ENAM DERAJAT CELSIUS DETAK JANTUNG DELAPAN PULUH ENAM BIT PER MENIT KADAR OKSIGEN SEMBILAN PULUH PERSEN*". This sentence has been normalized in the form of the appropriate number previous step. If the decapitation is described in the above process "*SU-HU, "BA-DAN", "TI-GA", "PU-LUH", "E-NAM", "DERA-JAT", "CEL-SI-US", "DE-TAK", "JAN-TUNG", "DE-LA-PAN", "PU-LUH", "E-NAM", "BIT", "PER", "ME-NIT", "KA-DAR", "OK-SI-GEN", "SEM-BI-LAN", "PU-LUH", "PER-SEN*", in which each word will be separated according to the Indonesian language rules in the previous step.

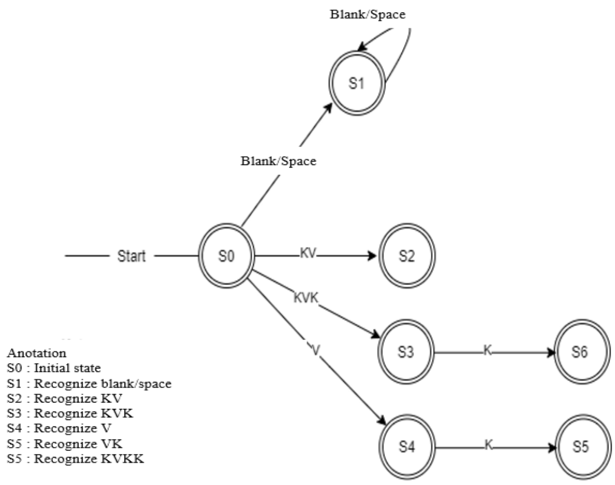

Figure 8. Health data FSA transition diagram

3.2. Hardware result

This section tries to show the results of the tools made, to ensure that the tool does not slide out of the hands of impaired people, the tool is glued to the wrist of impaired people, while the details of the tool can be seen in Figure 9 shows how the tool is made and how to use the tool by clamping the max 30100 sensors on the thumb of a visually impaired person for approximately 1 minute to get accurate data for analysis.

Figure 9. The final result of the created tool

3.3. Measurement

Testing was performed fifteen times for each syllable, for date, time, or health data as in Table 3. Table 4 shows the test results that show the accuracy of the test obtained a value of 100% for each data read by the sensor providing the appropriate beheading and giving the appropriate sound. The results of tests performed on the sensor are shown in Figures 10-12. Figure 10 shows the accuracy test of the temperature sensor which is compared to the tools that are already sold freely on the market. The average margin value is 0.29 the results show that the sensor accuracy level reaches 99.71% indicating that the sensor is very good at reading the body temperature of the visually impaired.

Another good thing that can be shown in Figures 11 and 12 is that our sensor was compared with a fingertip oximeter by testing 82 times, while the results show the average error is at 2% accuracy to measure heart rate, and 5% for the average error in testing oxygen levels, so it can be said that the tool made has a fairly good accuracy compared to tools that have been sold in the market today. To get the best accuracy value for the sensor, the testings were done by comparing the placement position of the sensor, whether on the finger, by placing it on the thumb or the pointing finger, or by placing it on the wrist, and the average heart rate difference is 9.85 beats per minute, with an accuracy of 88.80%, and the average difference in oxygen levels is obtained from 9.46 with an accuracy of 89.78%, the results on the finger show a better value.

Table 3. FSA testing

Push button	Text	Classification word K-V	Beheading words	1	2	3	4		15
1×	*HARI INI TANGGAL TIGA BULAN AGUSTUS TAHUN DUA RIBU DUA PULUH SATU*	KVKV VKV KVKKKVK KVKV KVKVK VKVKKVK KVKVK KVV KVKV KVV KVKVK KVKV	KV-KV V-KV KVKK-KVK KV-KV KV-KVK V-KVK-KVK KVKVK KV-V KV-KV KV-V KV-KVK KV-KV	√	√	√	√	√	√
2×	*SEKARANG JAM DUA BELAS NOL NOL*	KVKVKVKK KVK KVV KVKVK KVK KVK	KV-KV-KVKK KVK KV-V KVKVK KVK KVK	√	√	√	√	√	√
3×	*SUHU BADAN TIGA PULUH ENAM DERAJAT CELSIUS DETAK JANTUNG DELAPAN PULUH ENAM BIT PER MENIT KADAR OKSIGEN SEMBILAN PULUH PERSEN ANDA SEHAT*	KVKV KVKVK KVKV KVKVK VKVK KVKVKVK KVKKVVK KVKVK KVKKVKK KVKVKVK KVKVK VKVK KVK KVK KVKVK KVKVK KKVKVK KVKKVKVK KVKVK KVKKVK VKKV KVKVK	KV-KV KV-KVK KV-KV KV-KVK V-KVK KV-KVKVK KVK-KVVK KV-KVK KVK-KVKK KV-KV-KVK KVKVK V-KVK KVK KVK KV-KVK KV-KVK VK-KV-KVK KVK-KV-KVK KV-KVK KVK-KVK VK-KV KV-	√	√	√	√	√	√

Table 4. FSA test results

Actual/prediction class	TP	TN	FP	FN
One-time press	180	0	0	0
Double press	90	0	0	0
Three presses	330	0	0	0

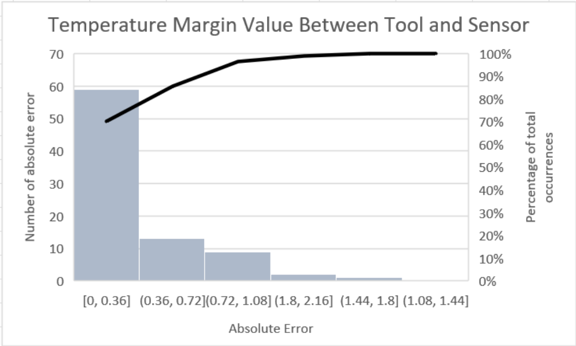

Figure 10. Temperature sensor accuracy test results

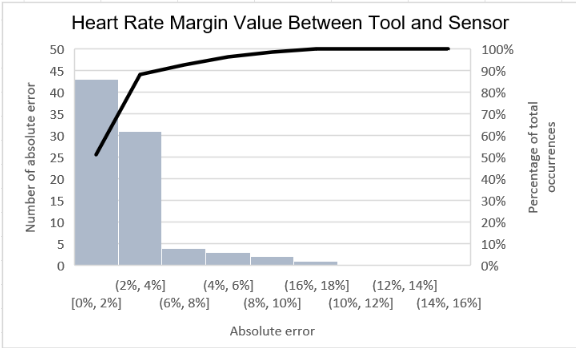

Figure 11. Heart rate sensor accuracy test results

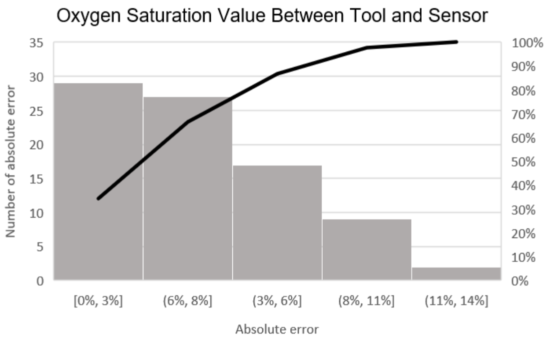

Figure 12. Oxygen saturation sensor accuracy test results

4. CONCLUSION

The use of the FSA method applied to TTS in terms of processing to recognizing or capturing and cutting words into syllable patterns according to Indonesian rules can be an alternative to the pronunciation process of the blind vision tool. Furthermore, the FSA can read any normalized symbol and input text given from the tool or web application. The application of FSA on the blind vision wrist tool in terms of cutting words into syllables has been successful and tested using the confusion matrix to get appropriate results both from absolute and not absolute words, by normalizing text changing numbers and symbols into the form of text, the introduction of vowel consonants in words, classifying and splitting words, and getting syllable results based on the processed FSA transition diagram.

By testing the FSA method using the confusion matrix to find the results of the accuracy values in the method, the accuracy rate is 100%. After testing the difference and accuracy of the tool as many as 84 tries within 3 days 12 hours were tested every hour. In the RTC DS3231 component with a mobile phone comparator, the author gets the result of the difference between push button 1x press and the comparison is 0, with an accuracy of 100%. When pressed twice, the comparison is a difference of 0.30 seconds with an accuracy of 99.97%. On the DS18B20 sensor with the infrared thermometer comparison results get a difference of 0.29 °C, accuracy of 99.71%. The max 30100 sensor with fingertip oximeter comparison results obtained a heart rate difference of 2.02 beats per minute and an accuracy of 99.76%. The result of the difference in oxygen levels of 4.79% and an accuracy of 98.43%.

The test on the max 30100 sensor with a comparison when placed on the fingers and wrists got the average result of the difference in heart rate of 9.85 beats per minute, the accuracy of 88.80%, and the average result of the difference in oxygen levels of 9.46%, accuracy of 89.78%. This method needs to be tested again on data with larger and more varied sizes to ensure the level of accuracy so that it can be known to what extent the accuracy of the FSA method itself is. For this reason, it is necessary to conduct further research by adding other sensors such as to measure a person's stress level and sleep quality as well as other measurements.

ACKNOWLEDGEMENTS

We would like to thank the Institut Teknologi PLN and the IT PLN Institute for Research and Community Services who have assisted in funding so that this research can be carried out properly. Also, we thank the Foundation of Visually Impaired named Yayasan Karya Tunanetra Peduli Bangsa which is willing to be a place of research.

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