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Reading Assistive Tool (ReaDys) for Dyslexic Children: Speech Recognition Performance

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ABSTRACT
Reading is one of the most challenging skills for dyslexic children to acquire at a young age. Therefore, it is crucial to assist dyslexic children in reading at an early age to avoid future reading difficulties that may have an impact on their academic progress and social emotions. However, the current conventional method of assisting dyslexic children requires trained personnel, a task that is arduous due to the limited school hours and dearth of accessible educational materials. Therefore, this study aims to develop an intelligence-assisted prototype system (ReaDys) for assisting dyslexic children's reading processes using a speech-to-text interface. The speech-based system was successfully developed using Microsoft Speech Application Programming Interface (API) with a specific interface design for dyslexic children. Microsoft Visual Studio and a C# Windows Form application are the technology tools used to complete the prototype development. Eighteen children were tested on 42 (forty-two) Malay words and phrases. After incorporating the Confusion Matrix, the prototype system achieved an accuracy of 75% with a 25% error rate. As a result, the developed prototype has the potential to serve as a technology-aided Malay language reading practice tool for dyslexic children that could be implemented to improve their reading skills.

Keywords: Reading Assistive Tool; Dyslexia; Human-Computer Interaction; Speech Recognition; Speech-to-Text

INTRODUCTION

Dyslexia is a type of language disorder that affects the learning ability of dyslexic children with a possibility of impairment in reading, writing, spelling, and calculating. A person with dyslexia often has difficulty learning, particularly in acquiring school-related skills like writing, reading, spelling, comprehension, and math. The primary difficulty that dyslexic children face in reading is a lack of decoding and spelling abilities and weaknesses in phonological awareness and manipulation (Share, 2021). Although the causes of dyslexia are still unknown, anatomical and brain imaging studies reveal differences in the development and function of the brain of a dyslexic individual. According to the International Dyslexia Association, dyslexia affects 10% to 15% of the world's population, while 10% to 15% of Malaysian primary school pupils suffer from the disorder (Anis et al., 2018). Due to their disability, families and teachers require additional support to facilitate their children’s learning, particularly when facing difficulties in acquiring fundamental learning skills such as reading, spelling, and writing.

One of the learning skills that is crucial for children to master is reading since it contributes to knowledge building and sharing (Husni & Jamaludin, 2009). However, because of their disorder, dyslexic children find it challenging to master this skill. Furthermore, researchers have stated that the majority of dyslexic children have problems with reading (Delavarian et al., 2017). Therefore, one of the ways assist dyslexic children in managing their reading disabilities, additional materials and learning tools must be developed and designed (Bigueras et al., 2020).

In Malaysia, awareness of the significance of early dyslexia intervention has increased. Early intervention may assist dyslexic children in acquiring the necessary reading skills. Nowadays, technology has become increasingly important in all aspects of life, including education. Utilising technology in education has numerous advantages that enhance teaching and learning. In addition, technology can motivate children to learn in a way that is both enjoyable and engaging (Görgen et al., 2020).

Technological advancements have impacted numerous facets of life; and dyslexia is not excluded from this expansion. Many developers have created numerous dyslexia-related technologies, including Dyslexia Quest, Me books, and Simplex Spelling Phonic. This development continues to expand to suit the needs and comfort of dyslexic children. When it comes to providing such support to the reading-aid application, speech technology can be used to assist children throughout the reading acquisition process. Speech recognition which is also known as Automatic Speech Recognition (ASR), is a technique that involves the implementation of codes and logical operation where the sound signal is converted into a sequence of words (Legoh & Chingmuankim, 2019, Siregar et al., 2019, Faisol et al., 2021). Speech recognition system has been widely used in various areas such as education, mobile assistant navigation, car technology, special needs assistance and many more. Thus, many researchers have developed and designed a system that incorporates speech recognition for educational purposes.

For instance, Athanaselis et al. (2014) have developed assistive reading aids for dyslexic Greek students utilizing the Agent-DYSL framework to support dyslexic students in reading fluently. The project is considered excellent as the evaluation result proved that the reading pace and reading accuracy of Greek dyslexic children have increased. Similarly, Avishka et al. (2018) used mobile applications to help dyslexic children practice reading. In their study, a mobile application that uses a speech recognition system to convert speech-to-text using Convolutional Neural Network (CNN) was developed, and implemented using TensorFlow. This project was built interactively, encouraging user participation in the system. In addition, some researchers had also studied the automatic speech recognition for specific languages such as Malay, Indonesian, Paite, Hindi, and others. In order to achieve this, automatic speech recognition using the Hidden Markov model and multisensory method was developed for the Indonesian language with high efficiency of 80% (Siregar et al., 2019). However, the system was only able to achieve a maximum efficiency of 80% because it is insensitive to the Indonesian alphabet because the speech API does not fully support the Indonesian language. In another study, Ali Al-Khulaidi & Akmeliawati (2017) created a speech-to-text application in Malay Language using the C# windows form application. The system was relatively good, with an accuracy of 92.69%.

Based on previous research, the developed systems were tailored to their intended audience's native language proficiency and implementation of a specific framework. Few studies focused on Malay-speaking children with special needs and were designed specifically for dyslexic or reading-impaired individuals. However, the system was tested on people who were not diagnosed with dyslexia. Automatic speech recognition has the potential to be implemented in order to develop a system to assist dyslexic children in improving their reading skills. Therefore, the purpose of this study is to develop a system to help dyslexic children improve their reading with correct Malay pronunciation. Hence, the objectives of this study are as follows:

1. To create a model for the intelligence-aided system to aid the dyslexic children reading practice by using Microsoft Speech Recognition.
2. To develop a speech-to-text interface in assisting the dyslexic children reading practice.
3. To analyze the accuracy of the system for recognizing words from the speech of dyslexic children based on the confusion matrix.

Consequently, the purpose of this study was to develop an Automatic Speech Recognition (ASR) system that could assist dyslexic children's reading development. This was accomplished through the implementation of a speech-to-text interface, which facilitated the transformation of spoken language into written text. In addition, a font type designed to improve readability for people with dyslexia was incorporated into the system. The system was designed in Windows Form Application using C# programming and implemented in Microsoft Visual Studio 2019. The accuracy of the system was determined by analyzing the confusion matrix pertaining to dyslexic children's word recognition from speech.

METHODOLOGY

This section describes the process of experimental design and system overview, including system architecture, system operation, graphical user interface, and experimental setup. The purpose of this study was to develop and investigate the impact of speech interface design in assisting reading proficiency among dyslexic children. This study was adopted by the principle of true experimental design and focuses on the implementation of control measures on a group of individuals with dyslexia, with the aim of examining the reinforcing effects associated with the utilization of this approach. This experiment's design concept includes several vital components, namely participant involvement, randomization, and control group implementation.

The study focused on the participation of a sample population consisting of children with dyslexia, for whom a system was specifically modeled and designed. The samples were chosen randomly among dyslexic circles to demonstrate the overall performance level of the constructed system. The main part of this study is the speech interface design intervention built specifically to help dyslexic children improve their reading skills. This cutting-edge technology has immense potential for creating an interactive and personalized approach for focused group of dyslexia in enhancing their learning experience. The speech interface was created using a model that was specifically designed for dyslexic children who require assistive tools to help them learn to read. The confusion matrix was used to evaluate the performance of the speech interface system. This matrix enabled a detailed evaluation of the accuracy in detecting the correct word or sentence pronounced by the participants and correcting reading errors. The accuracy percentage obtained, offered a quantitative measure of the successful speech interface designed. The outcome of this measurement in accuracy performance was based on the word selected during the testing session. Based on the principles of the experimental design, the methodology process flow was created, as shown in Figure 1.

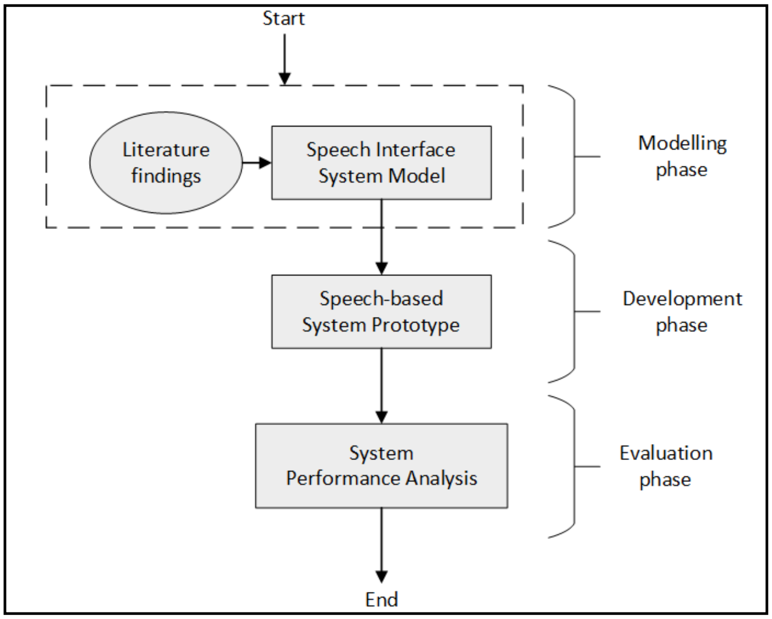

Figure 1. Research Methodology Process Flow

The processes are divided into three phase, as indicated in Figure 1, based on the elements identified during experimental design stage. The initial stage of the research involves the modeling phase, an examination of relevant literature and study in assessing the acceptance of the speech designed. The subsequent stage entails the creation of a prototype for a Speech-based system, while the final phase encompasses the evaluation of said system. This evaluation phase entails the measurement of accuracy and error rate, utilising the confusion matrix as a basis.

Modeling Phase

This phase involves the identification assistive reading tools modeling and investigation of previous similar research studies. The objective of this phase is to focus on understanding and specifying the contextual use of a speech-based system into the proposed system. The activity is to investigate the evolution of the reading system tools in special needs education, current methods used for early reading children's assistive tools, and interface design with speech interaction style. It includes the level of vocabulary used for the learning session. The lexical items were gathered from the Primary Data Collection Method (PDM) as well as from a dedicated intensive course conducted at the primary school. The selection of words was compiled according to the recommendations of the PDM and the primary school committee. These words are intended to be utilised as a grammar text within the Microsoft Speech Recognition Engine. The discovery is employed in the design of the prototype modelling system prior to advancing to the development stage.

Development Phase

The second phase is the development of a new speech-to-text interaction style for dyslexic children in the early stage of reading using Microsoft Speech Recognition Software Development Kit (SDK). The development of the prototype is based on the modelling conducted during the previous phase according to the findings of the literature. Several tools were used to yield the complete development system prototype by using C#, Microsoft Visual Studio, Microsoft Speech Recognition SDK, Windows Speech Recognition library, and database technology.

System Architecture

Microsoft Visual Studio as a program editor and Microsoft Speech Application SDK as a support to the speech recognition library in handling the speech recognition were used to implement the automatic speech recognition system using the C# Window Form Application. The users interact with the system through Graphical User Interface (GUI) using input speech and devices. The speech recognition engine then interprets the speech signal to the text output through speech API. The architecture of the system is shown in Figure 2.

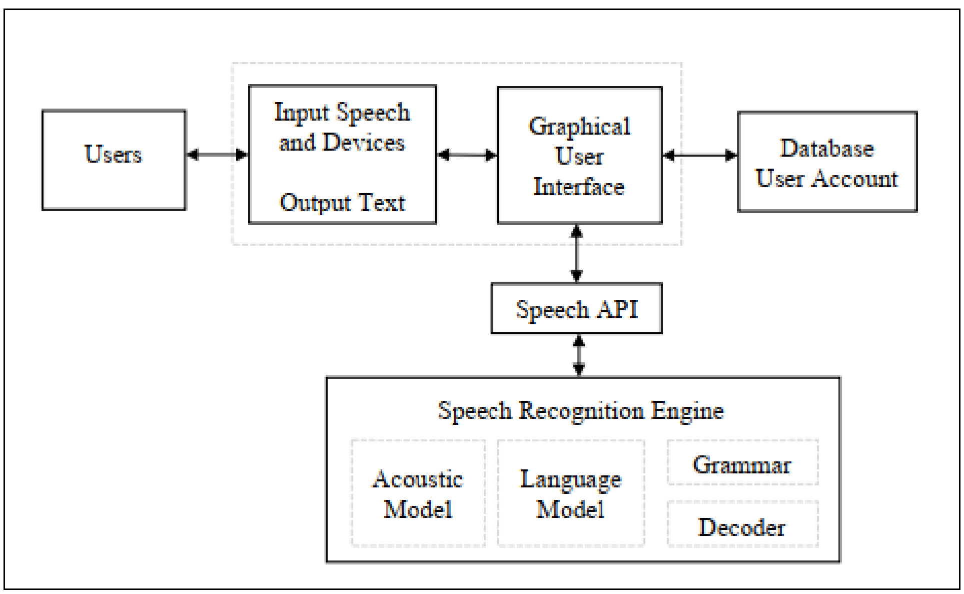

Figure 2. Architecture of ReaDys System

There are four speech recognition engine databases: the acoustic model, the language model, the grammar, and the decoder. The acoustic model is a statistical description of phonemes, and discrete sounds that are combined to form a word in spoken language. This model describes the sound of language acoustic that can recognize the characteristics of an individual user's speech pattern and acoustic settings. Next, the language model is a file used to recognize speech by the speech recognition engine which contains an extensive word list. The quality of a speech recognition system depends on the recognizer's language and acoustic model and on the algorithm's effectiveness in processing and searching for input sounds, while grammar is the list of words and phrases to be recognized by the system. The speech recognition system is the most crucial part, where it limits the number of recognized words and phrases. In this work, the words and phrases were loaded into the grammar section in the speech recognition engine. Lastly, the that decoder is responsible for converting voice feature extraction into text.

Speech System Design

Implementing the automatic speech recognition system starts a windows form application by launching the Microsoft Visual Studio. Then, a new C# windows form application was created with the project name. After that, System.Speech library needs to be added before creating any program with a speech recognition system in C#. The grammar feature must be added to the Speech Recognition Engine to enable the system to recognize the targeted words or phrases. The words and phrases that were loaded in Grammar List are presented in Table 1.

The grammar instance and the grammar builder objects were initialized before the program started. After that, the grammar was loaded into the speech recognizer, followed by the event handler. Then, the main menu appears on the screen. The user has the option to click on the easy, medium, or hard sections. The recognition does not commence unless the "speak" button is clicked, and the user utters the word once the button is clicked. The "Recognize_SpeechRecognized" method is invoked if the speech is recognized. The result property of the event handler displays the word. Lastly, the system continues until the "exit" button is clicked. The flowchart of the main program is illustrated in Figure 3.

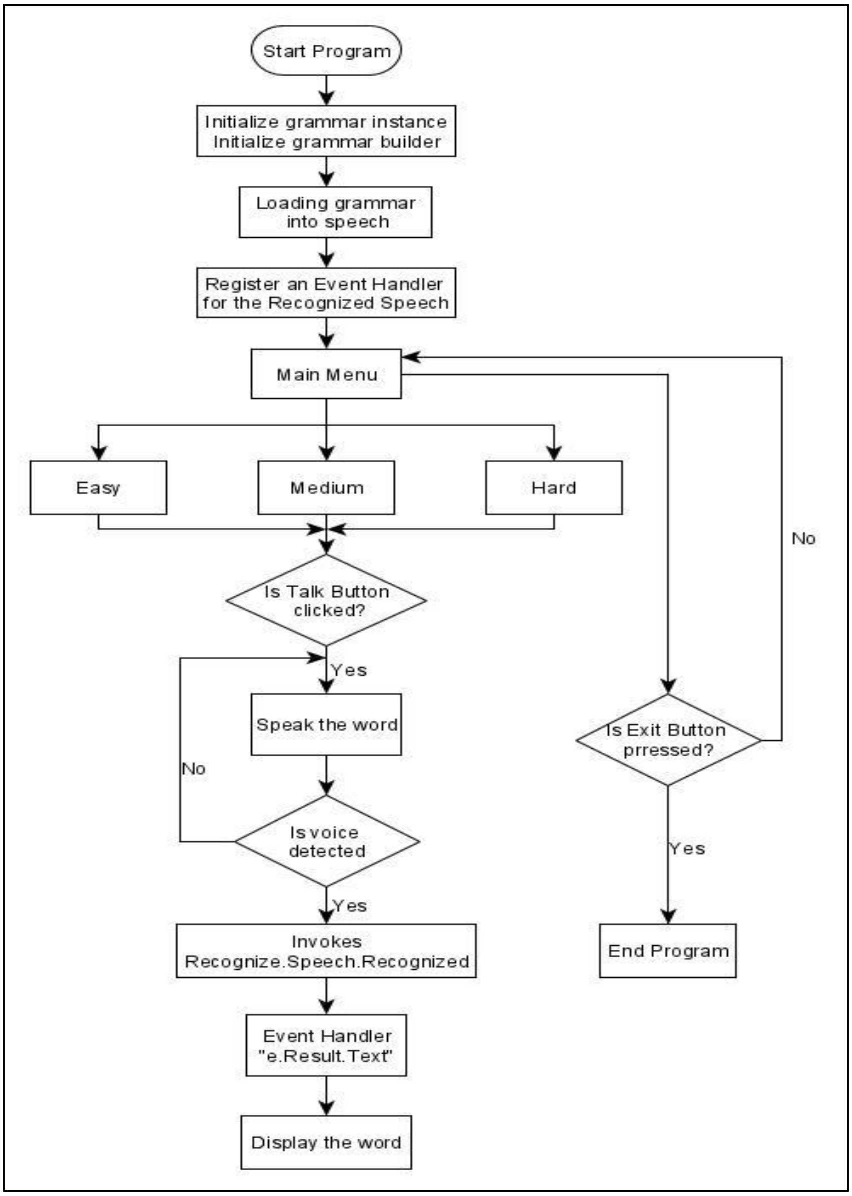

Figure 3. Flowchart of ReaDys System

Evaluation Phase

Sample data collection is obtained from the testing session involving dyslexic children with guidance from their teachers or parents. The third objective is to evaluate the performance of the proposed speech interface system for dyslexic children in terms of accuracy based on the confusion matrix. The analysis is conducted to evaluate the performance according to the parameters of the confusion matrix as presented in Table 1.

Table 1
Confusion Matrix

Parameters	Definition
True Positive (TP)	Predefined words in the speech recognition system and system correctly recognized word.
True Negative (TN)	Unconfused words, correctly recognized words that have not been predefined in the speech recognition system.
False Positive (FP)	Confused word, recognized word but merge correct and incorrect words.
False Negative (FN)	Unrecognized all words wether it is predefined or not.

The following formula is used to calculate the system's performance based on the Confusion Matrix:

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN} \times 100\% \quad (1)$$

$$Error\ Rate = \frac{FP+FN}{TP+FP+TN+FN} \times 100\% \quad (2)$$

RESULT AND DISCUSSION

This section presents a discussion of the findings obtained and the organization of the study based on its objectives. It includes a system model that provides the framework and guide to system development, a system prototype presented in the form of a graphical user interface that has speech elements, and the evaluation of test sessions for the system that has been developed.

System Model

The model system is established to prepare an appropriate speech interface system based on previous research findings in helping children with dyslexia for reading practices as mentioned in objective 1. As a model system and in preparation for the development of a prototype system, the following highlights of the study's findings serve as its foundation.

1. Letter selection is an important factor to consider when forming words or phrases with the combination consonant (k) and vowel (v), with an emphasis on the use of auditory and sound elements (Stein, 2022).
2. Low cost and speedy developmental prototype could be used and utilizing Automatic Speech Recognition system provided in Microsoft Speech Recognition SDK (Siregar et al., 2019).
3. Computer utilization as an educational tool will enhance the teaching process especially for teachers and students with disabilities (Basahel et al., 2022; Gupta et al., 2021b).
4. Learning the correct phoneme and grapheme is essential for children during the early reading process. Listening and imitating sound are implemented and realized through speech interface system model (Denton et al., 2021).

Therefore, in the modeling process, words and phrases selection is the most important part to be considered dyslexia children encaounter challenges with specific letters and the arrangement of the letters within word. These children often confuse between letters that look alike such as 'b' and 'd', 'm' and 'w', and other letters that share similar shape (Alamargot et al., 2020; Hebert et al., 2018). The Malay words and phrases used in this system consisted of blended consonant (k) and vowel(v) letters namely v+kvk, v+kvkk, kv+kv, kv+vk, kv+kvk, and kvk+kvkk.

Therefore, the tested words and phrases per system level are listed in Table 2, while the additional words and phrases not included in the grammar list to create confusion in the system are tabulated in Table 3. The additional words are used to observe the performance of the system in detecting the words or phrases that not are included in the grammar list. The modeling process begins with the addition of words and phrases to the grammar list in the Speech Recognition SDK.

Table 2
The tested words and phrases

Easy	**Medium**	**Hard**
Abah	Mana buku	Saya suka makan
Adik	Mana mata	Saya ada adik
Ibu	Nama saya	Hari ini mendung
Abang	Itu kaki	Ini ibu saya
Kakak	Hari ini	Saya suka tulis
Saya	Hari raya	Saya ada gigi
Mahu	Tolong saya	Mana buku abah
Tahu	Mahu tahu	Saya kuat makan
Hari	Huru hara	Kakak beli bunga
Lari	Lari dulu	Abah ada kebun

Table 3
The Additional Words and Phrases

Easy	**Medium**	**Hard**
Kamu	Suka hati	Saya suka tidur
Kami	Hari jadi	Abah pegi kerja
Dagu	Baju baru	Ibu masak sayur
Tidur	Tidur lena	Abang makan ikan

System Prototype
The system prototype, known as ReaDys, was successfully developed using the model established in the previous phase in order to achieve Objective 2, as outlined in the Introduction section. The speech interface system was developed using Microsoft Speech Recognition SDK

with interactive Graphical User Interface (GUI) to provide all the information about the system. Based on Figure 4.1 until Figure 4.4, the system consists of the main menu and three levels of word categories; easy, medium, and hard. Every level has text boxes to display the recognized words or phrases. Furthermore, the user interface controls the 'speak' button to enable the system to recognize the input voice and the 'stop' button to disable the system recognised input voice. The 'x' button can be clicked to quit the program, with maximize and minimize buttons on the upper right side of the user interface. In order for the system to function properly, the navigation flow had to be simple and easy for users (children) to understand (Bower, 2017).

Furthermore, the list box is used to display the words and phrases loaded in the grammar feature. Figure 4.2 until Figure 4.4, present the data on the recognized speech, confidence score, and the duration of the appearance of the recognition on the screen. The system also uses Open Dyslexic font type from https://opendyslexic.org/, which is provided for free by the organisation and specially designed for dyslexic children. In addition, the interface designs depicted in Figure 4.2, Figure 4.3, and Figure 4.4 exhibit a uniform background and maintain consistent placement of the word/phrase and other functional buttons, such as the microphone symbol, within the interface (Bower, 2017). As a result, the GUI design has made it beneficial to children with dyslexia, as they are less likely to confuse letter forms and avoid seeing words and letters in mirror images (Gupta et al., 2021a). Moreover, children with dyslexia are often distracted by their surroundings, so they require engaging components on the interface to keep them focus on the screens and perform the reading practice session (Srivastava et al., 2021). The spoken interface has been developed with a consistent style to prevent children from becoming confused when navigating the system. In view of prototype development, the ReaDys system's speech interface has been successfully developed with appropriate elements such as font type, button position, navigation flow, and appealing background to attract users (children) and easily for instructors to continue using the system as a reading practice tool.

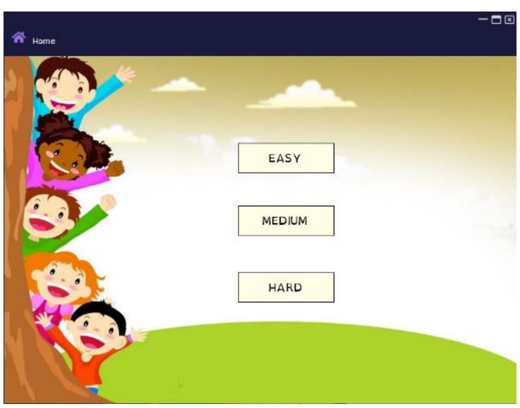

Figure 4.1 Main Menu

Figure 4.2 Level Easy

Figure 4.3 Level Medium

Figure 4.4 Level Hard

System Evaluation

Using a confusion matrix calculation, the performance of the speech recognition system in achieving objective 3 was evaluated to determine its accuracy. After the development is complete, the system setup.exe was published using Click Once in Microsoft Visual Studio and is ready to be used on the respondent's laptop or PC. Forty-two (42) words and phrases, including twelve (12) words and phrases that were not included in the grammar list, were tested on eighteen (18) respondents to determine the accuracy of the system. The respondents were children between the ages of seven and twelve. The research was conducted with the permission of the Research Ethics Committee of Universiti Teknologi MARA, Shah Alam. The assumption was made that there were no variations in the ages of the children. A total of twelve (12) words and phrases were incorporated into the testing procedure in order to assess their integration with the existing set of thirty (30) words and phrases from the grammar list. A comprehensive analysis was conducted on a dataset comprising 756 observations to assess the accuracy and error rate in relation to the testing session.

In order to analyse the performance of the system in terms of accuracy, the confusion matrix technique was used to evaluate the data (Karanasou et al., 2011). The data collected from the testing session was evaluated based on the confusion matrix of the recognized words from the speech of dyslexic children. The output was labelled with parameters; true positive (TP), true negative (TN), false positive (FP), and false negative (FN). True Positive (TP) refers the correctly recognized words or phrases; in which the system correctly recognized the words or phrases predefined in the grammar list of the speech recognition system whilst the speaker says that word. For example, if the speaker says 'abah', it will be true positive (TP) if the recognized word on display is 'abah'. In contrast, False Negative (FN) is unrecognized words or phrases weather it is predefined or not. True Negative (TN) is the unconfused words or phrases which indicates that the words being spoken by the speakers are not predefined in the speech recognition system, and the system is not confused with the words or phrases that have been predefined in the grammar list. For an example, if the speaker says 'kamu', which is not included in the grammar list, the system is not confused with the words and phrases predefined in the grammar list. However, it will be a False Positive (FP) if the system confuses the words or phrases with the predefined words or phrases in the grammar list.

Therefore, the system can be considered accurate when the value of TP and TN are higher than that of FP and FN. Table 4 shows the overall testing of sample data that were collected through out the testing session.

Table 4
Tested Data (TP: True Positive, FN: False Negative, TN: True Negative, FP: False Positive)

Respondent	TP	FN	TN	FP
1	28	2	0	12
2	29	1	0	12
3	21	9	5	7
4	23	7	6	6
5	28	2	2	10
6	29	1	5	7
7	29	1	5	7
8	23	7	5	7
9	24	6	8	4
10	28	2	6	6
11	27	3	1	11
12	28	2	6	6
13	29	1	5	7
14	29	1	6	6
15	25	5	8	4
16	26	4	5	7
17	29	1	5	7
18	28	2	6	6
Total	**483**	**57**	**84**	**132**

Based on the results, it can be concluded that the system has demonstrated a satisfactory performance, as it successfully recognizes words or phrases with an accuracy rate of 75%, while exhibiting an error rate of only 25%. The system can achieve higher accuracy if the number of TN is higher than FP. However, the system needs clarification on undefined words and phrases and the predefined words and phrases in the grammar list. The system became confused when it came across words or phrases with the same ending pronunciation sound, or when the sound of the words was nearly identical. For example, the word 'kamu' that was not predefined is being recognized as 'tahu' or 'mahu' when the children spoke to the system. Furthermore, the system also needs clarification when the undefined phrases contained the same word as the predefined phrase. For example, the phrase 'hari jadi', which was not included in the system, was confused with the phrases 'hari ini' when the children uttered the phrases. This resulted in the system being unable to achieve a higher number of true negative (TN). As additional feature, the system used the confidence score to determine the lowest matching score acceptable to trigger an interaction. The confidence score was originally developed for speech recognition, with a high confidence score indicating correct recognition and a low confidence score indicating incorrect recognition. In this system, when the confidence scores fall below 0.6, the system will not recognise the word or phrases.

As overall findings, the results show a satisfactory performance with 75% accuracy in recognizing the words and phrases through speech interaction between users and speech engine due to the satisfactory number of respondents involved during the testing session. Obtaining the participation of dyslexic children to undertake system testing is relatively difficult, as they have various priorities and must complete the testing at the appropriate time with their thoughts, feelings, and readiness (Snowling et al., 2020). As a result of this constraint, the performance measures of the system produce a limited result. However, this method has demonstrated improved efficacy and the capacity to assist children with dyslexia in practising reading skills, thereby boosting their self-confidence and academic success.

CONCLUSION

In conclusion, an early intervention is crucial to teach dyslexic children to read. Therefore, speech recognition technology is one of the methods for helping dyslexic children improve their reading skills. An automatic speech recognition system for early reading for dyslexic children was developed and tested. The system was implemented in Microsoft Visual Studio and Windows Form Application as a program editor using C# as a programming language. Furthermore, the system was tested on the children, and all the data were calculated using a confusion matrix. The system is relatively good in that it can accurately recognize words spoken by dyslexic children up to 75%, with a 25% error rate.

The speech-based interface system of ReaDys has been developed successfully, and it has been demonstrated that the system can help children with dyslexia improve their reading skills. Therefore, this strategy may have enhanced engagement by providing an interactive experience through speech commands that will capture their attention and maintain their interest throughout the reading practice session. Moreover, the speech-based system could track children's performance based on their individual needs and progress while adjusting the level of difficulty to optimize the learning session. However, there are still some elements that need to be improved to get this reading aid system to be more effective for children with dyslexia in general and all children who are still in the early stages of learning to read. One of the limitations of this study is that the prototype system is only developed on the desktop platform. Moreover, in terms of grammar, the words chosen are the basic words consisting of a combination of words with a consonant (k) and vowel (v) such as v+kvk, v+kvkk, kv+kv, kv+vk, kv+kvk, and kvk+kvkk. Therefore, it is recommended that future research uses the speech acoustic model instead of grammar to increase the recognition accuracy of the automatic speech recognition system. Lastly, the system should be developed to make it more compatible to be used on other platforms, not limited to desktops, smartphones, and online usage. This system will be portable thanks to operating systems like iOS and Android. More research is needed to improve the current approach to better cater to and assist dyslexic children in improving their reading abilities.

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Conflict of Interest

The authors declare no conflict of interest.

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