International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 10-No.3 (2024) pp. 427-433
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

A Comparative Study for Virtual Personal Assistants (VPA) and State-of-the-Art Speech Recognition Technology

Khalid Mohammad JABER[1]*, Mohammed LAF[2], Ahmad AA ALKHATIB[3], Amani Khamis AbedAlghafer[4], Mohammad ABDUL JAWAD[5], Amal Qassed AHMAD[6]

[1]AL-Zaytoonah University of Jordan, Department of Computer Science, Amman-Jordan
* **Corresponding Author Email:** k.jaber@zuj.edu.jo - **ORCID:** 0000-0002-8458-401X

[2]AL-Zaytoonah University of Jordan, Department of Software Engineering, Amman-Jordan
Email: lafi@zuj.edu.jo **ORCID:** 0000-0003-1893-9510

[3]AL-Zaytoonah University of Jordan, Department of Software Engineering, Amman-Jordan
Email: paselah@gmail.com **ORCID:** 0009-0003-0374-6203

[4]AL-Zaytoonah University of Jordan, Department of Cyber Security, Amman-Jordan
Email: ahmad.alkhatib@zuj.edu.jo - **ORCID:** 0000-0002-1369-1184

[5]AL-Zaytoonah University of Jordan, Department of Software Engineering, Amman-Jordan
Email: m.abduljawad@zuj.edu.jo **ORCID:** 0000-0003-4581-1299

[6]AL-Zaytoonah University of Jordan, Department of Electrical Engineering, Amman-Jordan
Email: amal.q@zuj.edu.jo **ORCID:** 0009-0000-3102-699X

Article Info:

DOI: 10.22399/ijcesen.383
Received : 17 July 2024
Accepted : 02 September 2024

Keywords

NLP (Natural Language Processing)
AI (Artificial Intelligence)
VPA (Virtual Personal Assistant)
SR (Speech Recognition)

Abstract:

Numerous types of virtual assistants have emerged as a result of the widespread use of smartphones, the expansion of their services, the tremendous advancements in automatic speech recognition and AI, and the growing reliance on virtual personal assistants (VPAs) for basic daily tasks like playing music, sending texts, making restaurant reservations, and getting weather updates. The popularity of virtual personal assistants is largely attributable to their convenient blend of user-friendliness and natural language interaction. This study comprehensively examines various virtual personal assistants powered by AI. It briefly overviews each, such as Microsoft Cortana, Samsung Bixby, Apple SIRI, Google Assistant, and Amazon Alexa. This study also includes a comprehensive overview of the state-of-the-art speech recognition used in virtual personal assistants. The findings show that each Virtual Personal Assistant has advantages, and a user may select any of them depending on his preferences and needs.

1. Introduction

Virtual personal assistants are only one example of the numerous technical applications that have accelerated our lives due to the enormous and incredible development in Artificial Intelligence (AI). A voice-activated virtual assistant, a personal assistant, is a piece of software that uses voice input from the user to answer questions in natural language, offer suggestions, and carry out tasks [1-10].

Virtual personal assistants, often referred to as conversational agents, can communicate with people via voice, text, or images to carry out daily chores like scheduling appointments, setting alarms, and making calls (audio and video) [6-19].

While standard search engines display millions of results in relation to a user-based query, comparing results and arriving at a file result, VPA is built to deliver a single outcome – current projections [2]. VPAs are quickly becoming capable, trustworthy, and beneficial assets. Some gadgets use a deep learning technique to enable high-clarity speech recognition [6, 3].

Microsoft Cortana, Apple Siri, Amazon Alexa, Google Assistant, Samsung S Voice, Samsung Bixby, IBM Watson, Alibaba, Almond, Kari, Hal, and numerous other devices have all been developed using spoken systems. These businesses have improved and designed their dialogue systems in various ways. Depending on the application and the

intricacy of the design, different technologies are utilized to create VPAs. [3]

This study will conduct a comparison among the most notable types within this category. The subsequent sections of the study are organized as follows: Section 2 delves into Understanding Speech Recognition, the foundational step in VPA development. Moving forward, Section 3 provides a concise overview of virtual assistants. Section 4 encompasses the virtual assistant study itself. Finally, the last section presents a table comparing the various VPAs discussed in this research.

2. Automatic Speech Recognition (ASR)

Automatic Speech Recognition translates speech signals to text using Natural Language Processing to determine the text's intent [3,20,21,22]. There are two types of speech recognition: speaker-independent, which detects anyone's voice without training, and speaker-dependent, which requires training to recognize a specific person's voice [8]. Mobile phones and smart devices both use this technology. Figure 1 depicts the general architecture of speech recognition.

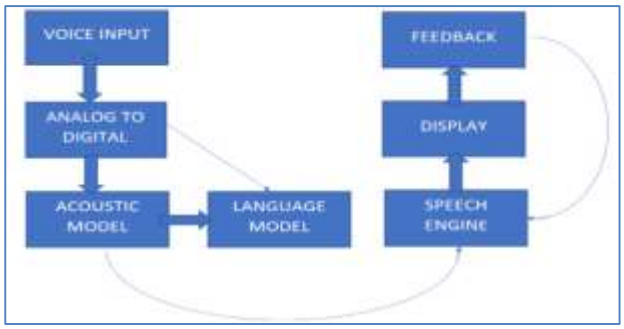

Figure 1. *The General Structure of the Speech Recognition System*

As depicted in Figure 1, the outlined architecture of the speech recognition system is as follows:

1. Input of Voice:
   - The user communicates using a microphone or an alternate audio input device.
   - The microphone captures the analog audio signal that includes the spoken speech.
2. Conversion from Analog to Digital:
   - The analog audio signal is transformed into a digital format via an Analog-to-Digital Converter (ADC).
   - The resultant digital audio signal becomes suitable for digital processing and analysis.
3. Acoustic Modelling:
   - The digital audio signal is pre-processed to extract pertinent features. This process often includes segmenting the audio signal into brief periods and applying window functions.
   - Characteristics such as Mel-Frequency Cepstral Coefficients (MFCCs) or representations in the form of spectrograms are extracted from each segment.
   - Acoustic models, which can be rooted in concepts like Hidden Markov Models (HMMs) or deep neural networks (DNNs), are harnessed to associate the extracted features with phonetic or sub-word elements.
4. Language Modeling:
   - A language model is utilized to anticipate the likelihood of word sequences within a given language.
   - The language model incorporates insights into word frequencies and grammatical structures.
   - Modern language models, including those built on neural networks like LSTMs or Transformers, are extensively employed for their capacity to capture intricate language patterns.
5. Speech Engine:
   - The speech engine is at the heart of the system, a pivotal component that integrates acoustic modeling and language modeling.
   - It amalgamates the probabilities derived from the acoustic and language models, generating the most probable transcription for the provided audio input.
   - Techniques such as beam search and dynamic programming are commonly employed to search for optimal transcription systematically.
6. Presentation and Output:
   - The outcome of the speech recognition process is the identified text.
   - This recognized text can be showcased on a display or serve as input for various applications, ranging from text-to-speech synthesis to tasks involving natural language processing.
7. Provision of Feedback:
   - Feedback mechanisms offer users insights into the accuracy or confidence level of the recognition process.
   - Confidence scores corresponding to identified words can be exhibited alongside the transcribed text.

- Systems are capable of supplying feedback through visual cues, auditory signals, or even tactile feedback.

3. Virtual Personal Assistant

A virtual personal assistant (VPA) is a software application or program powered by artificial intelligence designed to carry out tasks, provide information, and assist users in various aspects of their daily lives. These assistants are typically accessible through electronic devices such as smartphones, computers, smart speakers, and other devices connected to the internet [10]. A VPA has the capability to collect data about the user's inclinations, mobile phone usage, and engagement on social media, as well as their calendars and emails. It can adapt itself to provide relevant information and personalized user assistance. Furthermore, a VPA enables users to command the device using voice, even during phone conversations [9].

Users should have the ability to interact with VPAs using everyday language. VPAs also find applications in education, healthcare, home automation, sales, and more. There are two primary categories of VPAs:

1. Integrated VPAs utilize versatile devices like Cortana and Siri [3].
2. Standalone VPAs use dedicated hardware, such as Google Assistant and Alexa [1].

VPA software is available in various applications and is often integrated into the operating systems (OS) of diverse developers' and businesses' products. This includes desktop and laptop computers, as well as devices within the Internet of Things (IoT) ecosystem.

While VPAs are developed through diverse programming languages and exhibit varying behaviors, they all fall within the realms of computer science and tackle similar challenges [12]. Figure 2 shows the general structure of the VPA system. The typical structure of a VPA system involves capturing user input, deciphering the user's intention, constructing a response, and then delivering that response back to the user.

4. Virtual Personal Assistant: Comparative Study

Virtual personal assistants represent a significant domain within artificial intelligence, spanning multiple languages. Numerous endeavors have focused on improving the results of automated

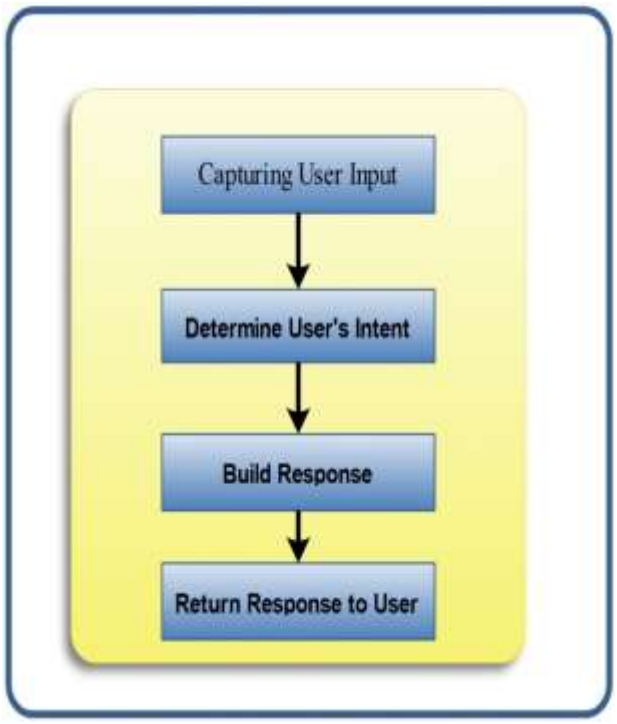

Figure 2. *The General Structure of the VPAs System*

speech recognition. Various summarization tools have been highlighted in the literature, including Amazon Alexa, Microsoft Cortana, Google Assistant, Apple Siri, and Samsung Bixby as shown in Figure 3.

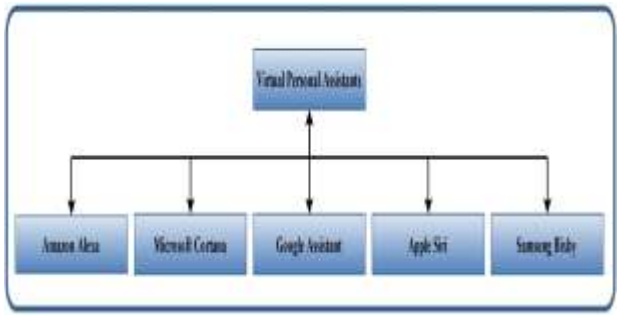

Figure 3. *Virtual Personal Assistant Applications*

4.1 Amazon Alexa

Since 2014, a virtual assistant has been available, serving as a captivating example of user interaction with a digital agent. Amazon's device, Alexa, stands out as a socially interactive tool that relies on interaction with others for its functionality. By assigning a name, gender, and personality to the agent, Alexa also takes on a sense of embodiment. In contrast to a casual response, these deliberate design choices encourage users to humanize the product, enhancing its appeal and perceived intelligence [4].

Alexa functions as a speech service, employing natural language processing techniques to execute AI tasks. It collects user information by recording voice requests or commands, which are then transmitted to AWS for processing, ultimately generating a suitable response [5]. It's important to note that Alexa is not entirely private; all audio, regardless of its content, is uploaded to the cloud and becomes accessible there [6].

Amazon Alexa offers several advantages as a voice-controlled intelligent assistant. Firstly, it provides a convenient and hands-free way to interact with devices and perform various tasks through voice commands. This feature is especially beneficial for individuals with mobility issues or who prefer a more natural interaction.

4.2 Microsoft Cortana

Microsoft's virtual personal assistant, Cortana, was created in 2009 by the company's developer team, and around that time, it began to be developed. It is available on the Android and iOS operating systems. It can access and modify reminders, identify the user's voice naturally, and respond to inquiries by leveraging data from Bing. While Cortana may be a personal assistant for the OS's built-in apps, it needs internet access to consult Bing for information [12].

Microsoft Translate serves as Cortana's user interface, and Bing is the search engine. Microsoft gives third-party users actions that, in response to explicit user requests or user context, give users functionality from their apps. Developers must start from scratch; actions are only available for Windows 10 Desktop, Mobile, and Android. It provides Cortana with remarkable SDK flexibility and the ability to handle a wide variety of intents and actions; nevertheless, developers must register their works, which is free and can likely be approved by a developer who works for Microsoft's Cortana team [12].

4.3 Google Assistant

Google Now, a component of the Google Home Page that debuted in 2016, was the previous name for the Google Virtual Assistant. It started as a chat app and evolved into a Google Assistant. It can respond to inquiries, formulate suggestions, and carry out tasks by making authorization requests for online services. Because of this, the service is very fixated on online accessibility [12].

Uses real speech patterns and imitations of human speech. Calls and schedules appointments. Several automation products, including Android smartphones, smart speakers, headphones, and security cameras, are compatible with Google Assistant [6]. Google Assistant supports many languages [13].

4.4 Apple SIRI

An Apple virtual assistant. Accessible on the majority of its device software bundles. Siri converts spoken words into text using automatic speech recognition (ASR). "Parsed text" is created by translating the written text using natural language processing. It scans distributed text using a query and objective analysis to find user orders and behaviors. Siri first appeared in 2011. Once the default operating system apps—Reminders, Weather, Messages, Email, Calendar, Contacts, Notes, Music, Watches, Web Browser, Wolfram Alpha, and Apple Maps—have been used, Siri can change the status of the file(s) [12]. The user device must be charged in order to digitize signals into digital files and collect data as audio. The files are given to a voice recognition system, which interprets the text based on context. Nouns, verbs, adjectives, and other words are filtered to analyze the text's integrative structure. After this complex and laborious process, the processed output is prepared and transferred as a digital file to the host. Now available in several languages in hands-free mode is Siri. Both the male and female voices are more authentic. Siri is only available on Apple devices [6].

4.5 Samsung Bixby

Samsung Electronics created the virtual assistant Bixby. It is compatible with various Samsung-branded equipment, mostly mobile phones but also some refrigerators. In 2017, Bixby debuted, replacing the S Voice assistant. The three components of Bixby are "Bixby Voice," "Bixby Vision," and "Bixby Home" (which, as of the most current One UI software update, has been replaced with "Samsung Free"). Samsung has only begun to develop, and you can text with Bixby and receive personalized weather updates, meeting reminders, news articles, and other information. Additionally, it gains more knowledge about what the camera captures and completes tasks. It can recognize different voices, tailoring its responses [7, 16].

5. Results And Discussions

After analyzing several research publications, Table 1 shows the differences among Amazon Alexa, Microsoft Cortana, Google Assistant, Apple Siri, and Bixby. This presentation offers a collection of intriguing comparisons.

- Device Compatibility: Each VPA analyzed in our study is designed to operate on specific hardware or operating systems. Alexa is supported by devices such as Echo Dot, Echo Plus, and Fire tablets. Cortana is intended for use with Windows 10. Google Assistant is optimized for Android smartphones. Additionally, Siri can be utilized on devices such as the Apple Watch, Mac, iPad, and iPhone.
- In terms of voice recognition and natural human interaction, Alexa exhibited the least favorable performance, while the most impressive results were achieved by Google Assistant [14].
- Technology Utilization: Siri and Cortana employed Natural Language Processing (NLP), while Alexa and Google Assistant relied solely on Natural Language Processing (NLP).
- Social Games (Utility): Among the VPAs, only Siri lacked utility in social games.
- Social Media: All VPAs, except Google Assistant, exhibited utility in this context [13].
- Provide User Email Updates: While Cortana and Google Assistant lack the ability to update users on their latest emails, Alexa, Siri, and Bixby offer this feature [13].
- Limitations of Alexa Regarding Data Protection: Alexa exhibits weaknesses in data protection. Challenges in Operating Google Assistant: Google Assistant presents difficulties in operation and consumes substantial data. Exclusivity of Siri to Apple Products: Siri's availability is restricted to Apple devices.

The following points are highlighted:

- In the research conducted by Tulshan et al. [14], speech-activated assistants (VPAs) exhibited subpar performance in speech recognition and human-like interaction. The reliability of these findings requires further scrutiny.

Additionally, the study by Reis et al. [13] asserted that all VPAs, except for Google Assistant, demonstrated utility on social media. The authors claimed that Google Assistant was unable to access Facebook. Nevertheless, these outcomes demand a more in-depth investigation.

5.1 Data Privacy Concerns

Addressing the significant concerns surrounding data privacy is essential for our analysis of virtual personal assistants (VPAs). These VPAs continuously gather and process vast amounts of user data, including voice commands, search queries, and personal information, to provide personalized services and improve user experience. However, this data collection practice raises critical privacy issues that must be considered.

One of the primary concerns is the potential for unauthorized access to sensitive information. As mentioned previously, VPAs often store recorded conversations and other user data on cloud servers, which can be susceptible to security breaches. Additionally, sharing user data with third parties, often for advertising purposes, is a matter of concern, particularly when users are not fully informed or do not give explicit consent, as mentioned previously.

Moreover, different VPAs have varying levels of data protection, with some offering more robust privacy measures than others. While certain services claim to anonymize data, there are ongoing debates about the effectiveness of these measures and the overall transparency of data handling practices. Users may not always be aware of what data is being collected or how it is being utilized, which can lead to a lack of trust in these technologies. To address these concerns, developers and companies must prioritize stronger privacy protections, including implementing end-to-end encryption, providing clearer data usage policies, and offering users more control over their personal information. Furthermore, updating regulatory frameworks to address the challenges posed by VPAs is crucial in ensuring user data is safeguarded effectively.

6. Conclusion and Future Work

In the modern world, almost every task has undergone digitization, allowing us to access various functionalities through smartphones. In parallel, virtual assistants serve as software programs that simplify life by offering services such as weather updates, setting reminders, creating shopping lists, and more. These assistants respond to speech or text commands, often through online chatbots. A pivotal role of voice-activated personal assistants is their capacity to handle user queries. Alexa, Cortana, Google Assistant, Siri, and Bixby leverage robust AI-driven search engines to retrieve internet-based information, ready to answer your inquiries promptly. Our study focused on the most prominent virtual personal assistant (VPA). We explored the fundamental structure of VPAs and provided an overview of the crucial role of the voice recognition system within them. A comparative analysis

Table 1. *The Variations between (Alexa,Cortana,Google Assistant, Siri, and Bixby)*

Key	**Alexa**	**Cortana**	**Google Assistant**	**Siri**	**Bixby**
Vendor [7]	**Amazon**	**Microsoft**	**Google**	**Apple**	**Samsung**
Devices	Echo Dot, Echo Plus Fire Tablet	Any device with Windows 10	Android smartphone, Google Home	iPhone iPad Mac Apple Watch	All mid-range and flagship Samsung Galaxy phones and tablets
Lunch date	2014	2009	2016	2011	2017
Wake Word	Alexa	Cortana	OK Google/ Hey Google	Hey Siri	Hi Bixby
Voice Recognition and human-free interaction [14, 15]	**7.91%**	**28.42%**	**59.80%**	**43.98%**	37.9%
Technology	NLP+CI	NLP	NLP+CI	NLP	NLP
Social Games (usefulness) [13, 16]	success	success	success	failure	success
Social media [13, 17]	success	success	failure	success	success
Inform the user about the latest emails [13, 18]	success	failure	failure	It possible	success
Limitations	Lack data security	trained by one user only	Not much user friendly, consume a of data	limited to Apple devices	Lack data security
Communication mode	Voice-based	Text+ voice	Text +voice	Text +voice	Text+ voice

encompassed Google Assistant, Apple Siri, Microsoft Cortana, Amazon Alexa, and Samsung Bixby. Our investigation revealed that these widely recognized VPAs could still benefit from further refinement. To ensure consistent comparability, we intend to replicate the experiments conducted in this study for future research endeavours.

While this study has provided significant insights into the current state and potential improvements of VPAs, there is still room for further exploration. Future work could benefit from integrating the data collection quality model for big data applications into evaluating VPAs. This model would ensure that the vast amounts of data collected and processed by VPAs meet high-quality standards, leading to more accurate and reliable assistant responses [23].

Future research could focus on data quality to enhance the overall performance of VPAs, offering users more refined and efficient interactions. Replicating our experiments with this model in mind could uncover new avenues for improving these virtual assistants, contributing to their ongoing evolution in a rapidly digitizing world.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] AV. López, (2019). Alexa & Google Assistant: The domestication and privacy implications of smart speakers and virtual personal assistants within the household (Doctoral dissertation, *Vrije Universiteit Brussel).*

[2] S. Lieberam-Schmidt, (2010). Analyzing and Influencing Search Engine Results: *Business and Technology Impacts on Web Information Retrieval. Springer Science & Business Media*. DOI: 10.1007/978-3-8349-8915-4.

[3] V. Kepuska, G. Bohouta, (2018). Next-generation of virtual personal assistants (microsoft cortana, apple siri, amazon alexa and google home). *In2018 IEEE 8th annual computing and communication workshop and conference CCWC* pp. 99-103. IEEE. DOI: 10.1109/CCWC.2018.8301638

[4] A. Purington, JG. Taft, S. Sannon, NN. Bazarova, SH. Taylor, (2017). Alexa is my new BFF. social roles, user satisfaction, and personification of the Amazon Echo. *In Proceedings of the 2017 CHI conference extended abstracts on human factors in computing systems* (2017) May 6 pp. 2853-2859. DOI: 10.1145/3027063.3053246

[5] F. Xie, Y. Zhang, C. Yan, S. Li, L. Bu, K. Chen, Z. Huang, G. Bai, (2022). Scrutinizing privacy policy compliance of virtual personal assistant apps. *In Proceedings of the 37th IEEE/ACM International Conference on Automated Software Engineering* pp. 1-13. DOI: 10.1145/3551349.3560416

[6] A. Mittal, A. Agrawal, A. Chouksey, R. Shriwas, S. Agrawal, (2016). A comparative study of chatbots and humans. *Situations* 2-2. DOI: 10.17148/IJARCCE.2016.53253

[7] AL. Nobles, EC. Leas, TL. Caputi, SH. Zhu, SA. Strathdee, JW, Ayers, (2020). Responses to addiction help-seeking from Alexa, Siri, Google Assistant, Cortana, and Bixby intelligent virtual assistants. *NPJ digital medicine* 29;3-1:11. DOI: 10.1038/s41746-019-0215-9

[8] SK. Gaikwad, BW. Gawali, P. Yannawar, (2010). A review on speech recognition technique. International *Journal of Computer Applications* 10-3;16-24. DOI:10.5120/1462-1976.

[9] A. Ravi, K. Subramanian, M. Srivastava, (2017). *Private communication*.

[10] R. Knote, A. Janson, M. Söllner, JM. Leimeister (2019). Classifying smart personal assistants: *An empirical cluster analysis*. DOI: 10.17170/kobra-202010302037.

[11] AL. Nobles, EC. Leas, TL. Caputi, SH. Zhu, SA. Strathdee, JW. Ayers (2020). *Responses to addiction help-seeking from Alexa, Siri, Google Assistant, Cortana, and Bixby intelligent virtual assistants. NPJ digital medicine* 29;3-1:11. DOI: 10.1038/s41746-019-0215-9.

[12] O. Bahceci, (2016). Analysis and Comparison of Intelligent Personal Assistants. Manuscrito no publicado. http://kth. instructure. com/files/92243/download.

[13] A. Reis, D. Paulino, H. Paredes, I. Barroso, MJ. Monteiro, V. Rodrigues, J. Barroso, (2018). Using intelligent personal assistants to assist the elderlies An evaluation of Amazon Alexa, Google Assistant, Microsoft Cortana, and Apple Siri. *In2018 2nd International Conference on Technology and Innovation in Sports*, Health and Wellbeing TISHW pp. 1-5. IEEE. DOI: 10.1109/TISHW.2018.8559503.

[14] AS. Tulshan, SN. Dhage, (2018). Survey on virtual assistant: Google assistant, siri, cortana, alexa, In Advances in Signal Processing and Intelligent Recognition Systems: *4th International Symposium SIRS 2018*, Bangalore, India, Revised Selected Papers 4, pp. 190-201. Springer Singapore, 2019. DOI: 10.1109/msp.2016.2617341.

[15] AS. Goh, LL. Wong, KY. Yap, (2021). Evaluation of COVID-19 information provided by digital voice assistants, *International Journal of Digital Health* 1, no. 1. DOI: 10.29337/ijdh.25.

[16] H. Jo, Hi Bixby: (2023). Determinants of goal-congruent usage and goal-congruent outcome in the artificial intelligence personal assistant context. *Journal of Information Science* 30;01655515231161554. DOI: 10.1177/0165551523116155.

[17] CM. Seródio Figueiredo, T. de Melo, R. Goes, (2022). Evaluating voice assistants' responses to COVID-19 vaccination in portuguese: quality assessment. *JMIR Human Factors (2022)* Mar 21;9(1):e34674. DOI: 10.2196/34674.

[18] U. da Silva Fernandes, GA. Barbosa, B. Azevedo, GD. Chagas, SD. Barbosa, RO. Prates, (2022). *Lessons Learned from Modeling the Interaction with Conversational Agents* DOI: 10.3389/fcomp.2022.744574.

[19] AQ. Ahmad, MA. Jawad, KH. M. Jaber, (2022). E-learning issues and solutions for students with disabilities during COVID-19 pandemic: Al-Zaytoonah University of Jordan case study. International *Journal of Evaluation and Research in Education* 11-4;2087-94. DOI: 10.11591/ijere.v11i4.22842.

[20] Khulood Abu Maria, Khalid Mohammad Jaber, and Mossab N. Ibrahim, (2018). A New Model for Arabic Multi-Document Text Summarization, International *Journal of Innovative Computing, Information and Control (IJICIC)*, 14(4);1443–1452.

[21] Tarek Kanan & Edward A. Fox, (2016). Automated arabic text classification with P-Stemmer, machine learning, and a tailored news article taxonomy, *Journal of the Association for Information Science & Technology*, Association for Information Science & Technology, 67(11);2667-2683.

[22] M. N. Ibrahim, K. A. Maria and K. M. Jaber, (2017). A comparative study for Arabic Multi-Document Summarization Systems (AMD-SS). *8th International Conference on Information Technology (ICIT)*, Amman, Jordan, pp. 1013-1022, doi: 10.1109/ICITECH.2017.8079984.

[23] Abdallah, M., Hammad, A., & AlZyadat, W. (2022). Towards a Data Collection Quality Model for Big Data Applications. *Lecture Notes in Business Information Processing*, 103–108. https://doi.org/10.1007/978-3-031-04216-4_11