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Machine-Learning based Analysis of Mobile Apps for People with Alzheimer's Disease

Roobaea Alroobaea[1], Mariem Haoues[2], Saeed Rubaiee[3], Anas Ahmed [4], Fahad Almansour [5]

[1]*Department of Computer Science, College of Computers and Information Technology, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia.*
[2]*Mir@cl Laboratory University of Sfax, ISIMS BP 242. 3021. Sfax-Tunisia.*
[3]*Department of Industrial and Systems Engineering, University of Jeddah, P.O. Box: 80327, Jeddah 21589, Saudi Arabia.*
[4]*Department of Industrial and Systems Engineering, University of Jeddah, P.O. Box: 80327, Jeddah 21589, Saudi Arabia.*
[5]*Department of Computer Science, College of Sciences and Arts Rass, Qassim University, Buraydah 51452, Saudi Arabia.*

r.robai@tu.edu.sa, mariem. haoues@isims.usf.tn, salrubaiee@uj.edu.sa

Abstract *: Although Alzheimer's is a progressive disease, individuals with Alzheimer's can have a normal life if they manage their lifestyle correctly and control the disease's symptoms. Currently, mobile apps provide a helpful solution for disease management assistance outside hospitals. Reviewing mobile apps users' feedback allows developers to better understand patients' needs and guarantee their satisfaction. In this paper, we analyze user reviews suggested on 10 selected mobile apps for individuals with Alzheimer's. A total of 1675 user reviews have been collected, including positive and negative opinions. This analysis has been performed based on machine learning and natural language processing techniques. The best performance was provided by the support vector machine classifier with accuracy equal to 99.43% in classifying user reviews into positive and negative reviews. The results of this analysis showed that users are not satisfied with the quality of the mobile apps available for people with Alzheimer's, especially the usability.*

Keywords — *Alzheimer's disease; Machine learning; Natural Language Processing; Opinion Analysis; Mobile apps.*

I. INTRODUCTION

Software development organizations compete to provide mobile applications (apps) that successfully satisfy users' needs. Worldwide, around 2.87 billion people use smartphones, where 47% say they cannot live without their devices [1]. Mobile apps are increasingly being integrated into many domains, including healthcare. Statistics indicate that over 318,000 mobile apps for healthcare (mHealth apps) are available in major app stores, with more than 270M people have downloaded a healthcare app [2].

In 2018, over 50M people were affected by Alzheimer's, and this number is expected to triple by 2050 [3]. Besides, Alzheimer's is the fifth-leading cause of death among the elder population [4]. Individuals with Alzheimer's must deal especially with physical, social, and emotional challenges. This can be stressful for them as well as their family members. To have a good quality of life, people with Alzheimer's disease need close care and regular surveillance.

In recent years, smartphones have become crucial for the family members of Alzheimer's patients [5]. Researchers have shown that mobile apps provide significant support for people with Alzheimer's in their daily lives. In this paper, we will focus on mobile apps that have been developed to assist people with Alzheimer's disease. Those apps should provide many services such as patient localization, people recognition, daily task reminders, etc. This will certainly help an individual with Alzheimer's as well as their families' members and caregivers.

Since its introduction in 1949 by the Canadian psychologist Donald Hebb [6], machine learning has been increasingly being adapted in different domains due to their problem-solving capacity, such as natural language processing, computer vision, robot control, etc. [7]. Healthcare is not an exception. Several machine learning classifiers have been successfully applied in healthcare for many purposes, such as early disease detection [8], reviewing mHealth apps [9], etc. This leads to the motivation to investigate the use of machine learning-based models to review the mobile apps for people with Alzheimer's available on both the Apple App Store and Google Play Store.

The question that we address in this paper is "*Are the users of Alzheimer's mobile apps satisfied with the provided functionalities?*". To answer this objective, we propose to collect data from the users' feedback on 10 selected mobile apps available for people with Alzheimer's and apply data prepossessing to construct a classification system using three selected machine learning classifiers (support vector machine, logistic regression, and random forest).

The remainder of this paper is structured as follows. Section 2 presents background information about Alzheimer's disease, reviews some related works, and provides a detailed description of different services provided by the Alzheimer's mobile apps. The proposed method and the used dataset are detailed in section 3. Section 4 presents the experiments' results. A detailed

discussion of the provided results is presented in section 5. Finally, section 6 concludes the presented work.

II. BACKGROUND AND LITERATURE REVIEW

This section presents background information about Alzheimer's, reviews some previous research studies that used the users' feedback to improve the mHealth apps, and provides the different features (*i.e.,* functionalities) offered by the mHealth apps for people with Alzheimer's and their caregivers.

A. Alzheimer's disease

Alzheimer's frequently affects older adults. However, around 2% of all people with this disease are younger than 65 years old [10]. This disease is a deadly disease that is associated with significant diagnosis and treatment costs. Moreover, it is significant in terms of costs for diagnosis as well as for treatments. Indeed, according to the Alzheimer's Association, Alzheimer's is predicted to cost the nation around US$1.1 trillion in 2050 [11].

Alzheimer's is defined by the Alzheimer's Association as a *"progressive neurological brain disease, which is caused due to the damage of nerve cells in parts of the brain"* [11]. Alzheimer's has mostly severe physical and psychological effects on the person with Alzheimer's and his family members. There is no single cause for Alzheimer's. However, researchers revealed that several factors could increase the risk of developing Alzheimer's, such as genetics and environmental factors [4]. Alzheimer's leads to neurodegenerative disorders that have severe effects on memory, longstanding movement, and oral abilities. Hence, people with Alzheimer's experience difficulties in finishing easy daily tasks, such as eating. Besides, they may forget recent events, the names of their relatives, etc. Consequently, to have a good quality of life, people with Alzheimer's need close care and regular surveillance.

Today's mobile devices (*e.g.,* Smartphones, Tablets, iPods, etc.) have become more prevalent to assist patients at low cost. Many mHealth apps have been developed to help people who suffer from Alzheimer's disease, their family members, and their caregivers. Besides helping people managing their daily activities, mHealth apps could keep people with Alzheimer's less agitated, busy, and stay safe in their homes [12]. For instance, Aljojo et al. [13] proposed a mobile app that uses facial recognition and location detection to support Alzheimer's patients in Saudi Arabia with early or middle stages. Hence, this app is mainly developed for caregivers. It used face recognition to improve daily communications, enhances the patients' ability to perform daily tasks, and maintain the patients' safety by tracking their location [13]. For example, it helps Alzheimer's patients recognizing their family members' photos, names, and relationships. Moreover, the authors proposed to use a bracelet to locate patients.

Although the number of mHealth apps for Alzheimer's is important, the number of patients that use an app is still restricted. This can be explained by the fact that Alzheimer's patients are not satisfied with the services provided by those apps.

B. Related Work

Analyzing the users' feedback on mHealth apps is used mainly to improve the apps' functionalities and satisfy users' needs. As is provided in Table 1, machine learning-based models have been widely used for this purpose. Researchers investigated many diseases such as mental health apps [14], diabetes self-management apps [15], bipolar disorder apps [16], smoking cessation app [17], etc. However, none of the previous studies investigated the use of machine learning-based models to review users' feedback on mobile apps for people with Alzheimer's disease. Some of these previous studies are outlined in brief below.

Oyebode et al. [14] used machine learning classifiers to review 105 mental health mobile apps from both Apple App Store and Google Play Store based on the user reviews. A total of 88125 user reviews have been used in this paper. This study used five supervised machine learning models: support vector machine, multinomial naïve Bayes, stochastic gradient descent, logistic regression, and random forest. As provided in Table 1, the best-obtained accuracy values have been given by the stochastic gradient descent and the support vector machine classifiers with, respectively, 89.43% and 89.39%. Then, they analyzed the collected user reviews to determine the positive and negative factors that impact the user opinion on the selected mobile apps. This study identified 21 negative factors (*cf.,* usability issues, content issues, ethical issues, etc.) and 29 positive factors (*cf.,* aesthetically pleasing interface, app stability, personalized content, etc.). Finally, the authors suggested recommendations to improve the identified negative factors to better satisfy the users' needs.

Benalaya et al. [15] used three machine learning classifiers (support vector machine, multinomial naïve Bayes, and stochastic gradient descent) to analyze user reviews on 10 selected diabetes self-management mobile apps. The objective of this analysis is to propose possible paths for diabetes mobile apps improvement according to a set of selected functionalities. The selected apps in this paper offer seven features (Medication and blood glucose measurement reminders, Self-monitoring and management, Management complication symptoms, Social media functions and communication, Architectural design, Security and backup, and Advanced quality factors). In this paper, the authors collected 3770 user reviews from the 10 best-ranked diabetes self-management mobile apps available in both Apple App Store and Google Play Store. Then, they applied data cleaning and data pre-processing to construct the dataset. Later, they used the three selected machine learning classifiers to classify the collected reviews firstly according to the selected seven features. Secondly, those reviews have been classified into positive opinion or negative opinion for each selected Feature. The results provided in this paper showed that the majority of the collected user reviews addressed the "Self-monitoring and management" feature with 44% and the "Advanced

quality factors" with 42% feature. Moreover, this study showed that 65% of the user reviews that addressed the "Advanced quality factor" feature were Negative. Whereas 68% of the user reviews that addressed the "Self-monitoring and management" Feature were Positive. Finally, the authors suggested some recommendations to improve the 10 selected apps. Regarding the performances of the selected classifiers, as provided in Table I, the support vector machine achieved the best accuracy with 95.80%.

Finally, Nicholas et al. [16] reviewed 48 bipolar disorder mobile apps available on Google Play and Apple app stores to identify unmet users' needs and better understand the users' expectations. Five different features have been provided by the selected mobile apps: symptom monitoring, information, screening and assessment, community support, and treatment. A total of 2173 user reviews have been analyzed in this paper. This study showed that 87.94% of the selected apps allow symptom monitoring. The majority of the apps' users agreed that bipolar disorder apps are simple and easy to learn. However, the majority of the negative reviews concern privacy and technical issues as well as the potential dangers of the used app. Moreover, users requested new features such as reminders, symptom tracking, etc.

TABLE I SUMMARY OF THE RESEARCH STUDIES THAT USED MACHINE LEARNING TO ANALYZE MOBILE APPS USERS' FEEDBACK

Research study	Dataset	Machine learning models	Accuracy
Oyebode et al., [14]	Mental mobile apps	**Stochastic Gradient Descent**	**89.43%**
		Support Vector Machine	89.39%
		Multinomial Naïve Bayes	89.07%
		Logistic Regression	89.07%
		Random Forest	87.69%
Benalaya et al., [15]	Diabetes self-management mobile apps	Multinomial Naïve Bayes	94.00%
		Stochastic Gradient Descent	95.60%
		Support Vector Machine	**95.80%**

C. Alzheimer's disease mobile apps features

In the literature, many researchers reviewed the mobile apps for people with Alzheimer's as well as their caregivers available on the market (*cf.*, [5], [13], [18], etc.) to determine the different features that are provided by those apps. For instance, Aljojo et al. [13] conducted interviews with caregivers living with patients with Alzheimer's and a specialist in neurology at a mental health hospital in Jeddah, Saudi Arabia, to identify what a mobile app should provide for both patients and their caregivers. Hence, according to this paper, a mobile app for people with Alzheimer's should mainly: (i) remind and notify the patient about important tasks and events, and (ii) track the patient and alert his caregiver when the patient crosses a predefined safe zone. In addition to the functional requirements, a mobile app for people with Alzheimer's should satisfy non-functional requirements as well, such as usability, accessibility, performance, etc. On the other hand, Gupta et al. [5] reviewed 60 mobile apps for Alzheimer's to extract the main services provided by each selected app. This study identified the following features: learning & caregiving, pillbox, schedule, doctor dairy, news, family & safe zone, music & games. The results of this study showed that among the collected 60 mobile apps, only five have been considered as useful based on the selected features (Carezone, Tweri Alzheimer Medical App, Alzheimer & Dementia, CURAAP, and Alzheimer Assistant). Moreover, the majority of the selected apps provide the learning, care-giving, pillbox, and GPS tracking features. Moreover, Choi et al. [18] reviewed and evaluated the functionality and the quality of mobile apps available for people with Alzheimer's or dementias using a mobile apps rating scale. 36 mobile apps for Alzheimer's have been collected from Google Play Store and Apple App Store. The results of this paper showed that two features have been widely offered by the selected paper, which are caregiving with 62.10%, and disease management with 55.60%. While only 8.3% of the selected apps provide the community and reminder functionality. However, a reminder is important functionality, especially for people with Alzheimer's disease. A person with Alzheimer's can forget new discussions or events. Moreover, the results of the selected app's evaluation mentioned that their quality was acceptable. Around 67.00% do not need an Internet connection, 25.00% allow video and audio lectures/tutorials, and 16.70% allow information sharing. Finally, Guo et al. [19] conducted a systematic literature review to evaluate 14 mobile apps for people with Alzheimer's to analyze their availability, content, features, and quality. The results of this study showed that around 64.00% of the selected apps allow the alert feature, 42.00% provide the self-care tips feature, and 35.00% allow the social networking capacity feature. This study mentioned that currently, the available apps for people with Alzheimer's do not meet their needs and maybe challenging to use. Based on our conducted literature review, we selected the common features provided by the available mobile apps for people with Alzheimer's as well as their caregivers.

Table II presents a detailed description of the provided features by the mHealth apps for Alzheimer's disease.

TABLE II ALZHEIMER'S DISEASE MOBILE APPS FEATURES AND THEIR DESCRIPTIONS

N°	Feature	Description
1	Face recognition	Recognizing people using the smartphone camera
2	GPS tracking device	The use of a bracelet, for example, provides patient's location in real-time
3	Alert notification	The use of notification for a new event or task and unknown place alert.
4	Task reminder	Reminders for events, daily tasks, taking medication, To-do list, etc.
5	Multiple interfaces	Provides interfaces according to the user (*e.g.*, patients, caregivers, etc.)
6	Adding pictures	The addition of pictures and information to help the patient is connected with friends and family.
7	Security and backup	The use of protection method or privacy policy (e.g., secure login).
8	Quality factors	The non-functional requirements such as usability, accessibility, etc.
9	Education	Provide basic information about Alzheimer's disease
10	Games	Offer games for people with Alzheimer's and weak short-term memory (*e.g.*, pairs matching, mental math, etc.).

As it is provided in Table II, mobile apps for Alzheimer's disease provide different features for people with Alzheimer's to help them managing their daily activities and keeping them save, such as face recognition, task reminder, games, etc. In addition, some features also are provided for caregivers, such as GPS tracking, education, etc.

III. MACHINE LEARNING FOR USER REVIEWS ANALYSIS OF ALZHEIMER'S DISEASE MOBILE APPS

This section provides a detailed description of the proposed method in this paper and the used dataset.

A. Method

Recall that the main purpose of this paper is to evaluate the mobile apps for people with Alzheimer's disease based on the user reviews. This evaluation will be effective in assisting developers in improving those mobile apps in the next release. Figure 1 illustrates the proposed approach in this paper.

As it is illustrated in Figure 1, the proposed approach in this paper consists of the following four steps:

1st step - data collection and data cleaning: To construct the dataset to be used in this paper, we firstly collected user reviews for the 10 best ranked mobile apps for people with Alzheimer's disease in both Google Play and Apple App stores using the Heedzy tool [20].

Then, the collected user reviews have been cleaned by removing reviews written in a language different from English and non-relevant information (*e.g.*, date, user's name, etc.).

Finally, we annotated the collected user reviews and classified them into two categories: positive opinion and negative opinion.

This step will be detailed in section III.B.

- **2nd step - Data pre-processing and Feature selection:** We applied the natural language processing techniques in the pre-processing of the data to be used by the selected machine learning classifiers, such as tokenize sentences, removing stop words, shorten repeated characters, etc.

Then, we deployed the Term Frequency-Inverse Document Frequency (TF-IDF) vectorizer in the reviews Vectorization.

Finally, we applied the feature selection using the *SelectFromModel* feature selection method in order to eliminate the irrelevant features.

This step will be detailed in section III.C.

- **3rd step - Machine learning classifiers:** Three selected machine learning classifiers (support vector machine, logistic regression, and random forest) will be used to automatically classify the user reviews into positive opinion or negative opinion.

This step will be detailed in section III.F.

- **4th step - Evaluation:** The evaluation of the three selected machine learning classifiers using the well-known metrics: Accuracy, Precision, Recall, and F-measure.

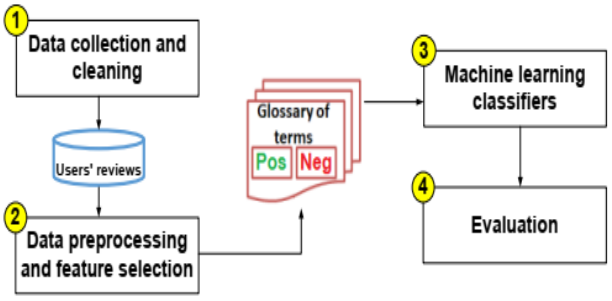

Fig. 1 The proposed approach to analyze the user reviews on mobile apps for Alzheimer's disease

B. Data collection and Data cleaning

To select the most eligible mobile apps for Alzheimer's disease to be used in this study, we performed a search on both Apple App Store and Google Play Store using the keywords: Alzheimer's disease and Alzheimer's. A total of 249 and 10 apps from Google Play and App Store, respectively, have been collected. Hence, the total number of the collected apps is 259.

The 256 collected apps are provided in different languages (*e.g.*, Spanish, English, French, etc.). Moreover, some of them are provided for people with Alzheimer's, while others are provided for their caregivers. To guarantee the quality of the user reviews, we excluded apps according to the following Exclusion Criteria (EC):

- **EC1:** Duplicate mobile apps (*i.e.*, available on both Apple App Store and Google Play Store) are

considered as one app. By applying this exclusion criterion, three mobile apps have been excluded from the total number, such as "Memory Exercises for Alzheimer's," "Alzheimer & You," and "CogniFit entraînement cérébral."

Consequently, the total number of mobile apps that have been kept after applying EC1 is 256.

- **EC2:** Exclude mobile apps where the last update was before 31st December 2019. By applying this exclusion criterion, a total of 221 apps have been excluded in this research study.

Consequently, the total number of mobile apps that have been kept after applying EC2 is 35.

- **EC3:** Exclude mobile apps without English or French interfaces. By applying this exclusion criterion, a total of five apps have been excluded in this research study (*e.g.*, Preguntas estimulación cognitiva, YoTeCuido Alzheimer, etc.).

Consequently, the total number of mobile apps that have been kept after applying EC3 is 30.

- **EC4:** Exclude mobile apps that only provide information about Alzheimer's disease and cannot be used by people with Alzheimer's. By applying this exclusion criterion, a total of five apps have been excluded in this research study.

Consequently, the total number of mobile apps that have been kept after applying EC4 is 25.

- EC5: Exclude mobile apps with less than five user reviews. By applying this exclusion criterion, a total of 15 apps have been excluded in this research study.

Consequently, the total number of mobile apps that have been kept after applying EC5 is 10.

TABLE III NUMBER OF THE USER REVIEWS COLLECTED FROM THE SELECTED APPS AND THEIR CLASSIFICATION

N°	App name	Rate	Number of reviews			
			Positive	Negative	Neutral	Total
1	MemoClock — The Dementia Clock	4+	13	10	0	23
2	Alzheimer's 40Hz Gamma Light & Sound Therapy	3+	10	12	0	22
3	HAMARU : Jeux cérébraux et entraînement	4+	14	12	1	26
4	Jeux de mémoire cérébrale pour adultes gratuits	4+	33	13	2	46
5	Entraîne ton Cerveau - Jeux de Mémoire	4+	208	30	4	238
6	Entraînement Cérébral CogniFit	4+	19	10	0	29
7	Jeux d'Alzheimer, Match	4+	30	12	1	42
8	Alz Test	3+	11	12	0	23
9	My House of Memories: Dementia & Alzheimer's App	4+	10	13	0	23
10	Brain Test : casse-têtes	4+	710	480	5	1190
Total			**1058**	**604**	**13**	**1675**

Consequently, the total number of the Alzheimer's disease mobile apps that will be used in this paper is 10 apps, where 8 apps are rated 4+, and 2 apps are rated 3+. Thereafter, we used the Heedzy tool [20] to collect the users' reviews from the 10 selected mobile apps. Thus, we collected user reviews from the selected 10 mobile apps. The total number of selected user reviews is equal to 1675, where 1058 are classified as Positive, 604 are classified as Negative, and 13 are classified as Neutral. Table 3 provides the number of the collected user reviews for each selected app and their classification into Positive, Negative, and Neutral. The majority of the user reviews that will be used in this study have been retrieved from the Google Play Store.

In our search to selected mobile apps for people with Alzheimer's disease, we noted that there are some differences between them. In fact, some of those apps tracking and face recognition feature that can be considered as indispensable for people with Alzheimer's and their caregivers. While other propose cognitive games that can be used by people with low computer skills and weak short-term memory (*e.g.*, Sudoku, Tic-Tac-Toe, etc.). Moreover, some apps allow detecting signs of early memory impairment due to Alzheimer's, such as the "Alz Test."

In Table 4, we give examples of user reviews and their classification into Positive opinion or Negative opinion. The first and second user reviews are classified as Negative. They are rated one star. These two user reviews include keywords such as "Nah," "uninstall," "annoying," etc. The third and the fourth user reviews are classified as Positive opinion. Both of them are rated five stars. They include keywords such as "Great," "Nice," "Thank," etc.

TABLE IV EXAMPLES OF USER REVIEWS CLASSIFICATION

User reviews	Classification	Rate
Requires a validated email. Even if it saves my data and test results, it's not worth it to me.	Negative	1
It's annoying. I uninstall after 10mn.	Negative	1
Great app. Very nice and easy to use	Positive	5
Thank you for developing this app! Cannot recommend it enough for those that are struggling with memory issues	Positive	5

C. Data pre-processing

To be used by the machine learning classifiers, the collected user reviews needs to be pre-processed. Data pre-processing is an indispensable step in this research study. This phase is based mainly on natural language processing techniques.

The data pre-processing step includes the following tasks:

- Remove punctuation, special characters, and numbers.
- Tokenize sentences, which means splitting the user reviews into tokens. Then, we convert tokens in lowercase.
- Shorten repeated characters (*e.g.*, "soooo baaaaad" is replaced by "so bad").
- Remove stop words (*e.g.*, "the", "of", "this", "and", etc.).
- Replace contraction and abbreviations with their basic forms (*e.g.*, "OMG" is replaced by "Oh My God," "don't" is replaced by "do not," etc.).

D. Data annotation

In this step, we will formulate the ground truth dataset by annotating each user review as positive or negative. Each user review is rated by other users using a scale of 1 to 5, where 1 star represents a "very dissatisfied" opinion, 2 stars represent a "dissatisfied" opinion, 3 stars represent a "neutral" opinion, 4 stars represent a "satisfied" opinion, and 5 stars represent a "very satisfied" opinion. The automatic annotation of the selected user reviews is done according to the following rules:

- Delete the "neutral" user reviews. The total number of those reviews is 13.
- Classify the "very dissatisfied" and the "dissatisfied" user reviews as Negative. The total number of those reviews is 604.
- Classify the "satisfied" and the "very satisfied" user reviews as Positive. The total number of those reviews is 1058.

Table 5 presents the total number of user reviews that will be used by the machine learning classifiers and their classification into Positive or Negative. As provided in this Table, the total number of user reviews that will be used in this research is 1662, where 1058 are Positive reviews, and 604 are Negative reviews.

TABLE V USER REVIEWS AND THEIR CLASSIFICATION

Sentiment polarity	Number of user reviews
Positive	1058 (63%)
Negative	604 (37%)
Total	1662

E. Data vectorization

In this phase, we firstly extracted unique, clean tokens from the user reviews in the ground truth dataset. However, machine learning algorithms cannot understand String data. Then, we applied the Term Frequency-Inverse Document Frequency (TF-IDF) vectorizer to create a document-term matrix that assigns a weight for each word [21]. In this matrix, the columns represent the features, and cells represent the Feature's weight.

F. Machine learning classifiers

In this section, we present the implementation of machine learning classifiers to automatically classify the collected user reviews into Negative opinion or Positive opinion. Among the different machine learning classifiers used in the literature, we selected the three widely used classifiers: support vector machine, logistic regression, and random forest. The training and testing of each selected model were performed using 10-fold cross-validation. The performance evaluation of the selected models is done using the following evaluation metrics: Accuracy (Eq. 1), Precision (Eq. 2), Recall (Eq. 3), and F1-score (Eq. 4) [22][23].

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

$$\mathrm{Pr}ecision(\%)=\frac{TP}{TP+FP} \quad (2)$$

$$\mathrm{Re}call\,(\%)=\frac{TP}{TP+FN} \quad (3)$$

$$F1-score(\%)=\frac{2*\mathrm{Re}call*\mathrm{Pr}ecision}{\mathrm{Pr}ecision+\mathrm{Re}call} \quad (4)$$

The references and introduced labels for the evaluation of the proposed models are provided in Table 6.

TABLE VI USER REVIEWS AND THEIR CLASSIFICATION

		Algorithm Label	
		Positive	**Negative**
Referenced label	**Positive**	Positive-Positive (TP)	Positive-Negative (FN)
	Negative	Negative – Positive (FP)	Negative-Negative (TN)

IV. EXPERIMENTAL RESULTS

In this section, we present the results of our conducted experimentation. In Table 7, we present the performance evaluation results of the three selected machine learning classifiers using the Accuracy (Eq. 1), Precision (Eq. 2), Recall (Eq. 3), and F1-score (Eq. 4) metrics. As is shown in this Table, the selected three classifiers provide promising results. The best accuracy score was given by the support vector machine classifier with 99.43%, followed by the logistic regression classifier with 99.10%. While the lowest accuracy score was given by the Random Forest classifier with 98.89%.

TABLE VII THE PERFORMANCE EVALUATION RESULTS OF THE THREE SELECTED MACHINE LEARNING CLASSIFIERS

Classifiers	Accuracy	Precision	Recall	F1-score
Support vector machine	99.43%	99.30%	99.70%	99.46%
Logistic regression	99.10%	99.30%	99.29%	99.19%
Random forest	98.89%	98.89%	99.28%	99.08%

In Table 8, we evaluate the performance of the selected classifiers according to the sentiment polarity (Positive and Negative). As it is presented in this Table, using the support vector machine classifier, we achieved 98.00% and 89.00% F1-score in classifying reviews into respectively Positive and Negative, while 98.00% and 88.00% have been obtained in classifying reviews into Positive and Negative, respectively using the logistic regression classifier. Finally, using random forest, we achieved an F1-score equal to respectively 97.00% and 87.00% in classifying Positive and Negative user reviews.

TABLE VIII EVALUATION METRICS FOR THE MACHINE LEARNING CLASSIFIERS BY SENTIMENT POLARITY

Classifiers	Polarity	Metrics		
		Precision	Recall	F1-score
Support vector machine	Positive	99	99	98
	Negative	96	86	89
Logistic regression	Positive	98	98	98
	Negative	96	86	88
Random forest	Positive	97	97	97
	Negative	95	85	87

v. DISCUSSION

The results provided in this paper proved that the users of mobile apps for people with Alzheimer's are not satisfied with the provided services in some of the selected apps, except gaming apps. For the majority of those apps, the number of Positive reviews is greater than the number of negative reviews. However, the number of Negative reviews is still important in some app. There is a major agreement of mistrust. Some reviews criticized the usability of mobile apps for people with Alzheimer's. They do not think that a person with Alzheimer's could use an iPad or smartphone (*e.g.,* "Ok confusion though. Can't see how it helps Alzheimer's.").

Moreover, we noted that the majority of the user reviews are written by the relative of a person with Alzheimer's disease. For example, some reviews started by "My mom has Alzheimer's, it is easy to play" or "My grandmother is playing it too this is so cool family game." Moreover, we noted that the majority of the mobile apps that are provided for people with Alzheimer's are games to train their memory. Around 79% of the user reviews on the selected mobile apps that include games (*e.g.,* HAMARU: Jeux cérébraux et entraînement, Jeux de mémoire cérébrale pour adultes gratuits, etc.) are Positive. People with Alzheimer's are enjoying those games since they are fun and keep them busy (*e.g.,* "Very easy, time-consuming and relaxing game. No time clock so no stress."). However, the Negative user reviews on those apps were mostly technical issues, such as "No sound!!".

Besides, some comments addressed the interfaces provided in mobile apps for Alzheimer's patients, which can be complex for them. Thus, data automation is an important driver for ease of use and, ultimately, for

satisfaction with the technology [15]. Moreover, some comments proposed to improve the gaming apps by adding more levels, for example, "Awesome. A good time killer. Needs more levels. And more challenging".

To improve the mobile apps for people with Alzheimer's, mobile apps developers should work on their usability, make the interfaces easier to use and to learn. Moreover, they should focus on improving the games and make them more fun.

VI. CONCLUSIONS

Reviewing users' feedback on mobile apps brings great ideas to improve those apps in the next release. In his feedback, a user may criticize a functionality provided by a mobile app, its quality, suggest a new improvement, etc. In this paper, we used three selected machine learning-based models to evaluate mobile apps for people with Alzheimer's disease. A total of 1675 user reviews, including positive and negative opinions, have been collected from 10 best-ranked mobile apps for people with Alzheimer's. We applied data cleaning and data prepossessing to prepare the dataset to be used by the three selected machine learning classifiers. The best results were provided by the support vector machine with accuracy equal to 99.43% in classifying user reviews into positive and negative reviews.

For future work, we are planning to analyze and review the negative user reviews deeply to identify the various reasons that may impact the usability of the mobile apps for people with Alzheimer's disease. Besides, focusing on mobile apps that help caregivers taking care of patients with Alzheimer's is also interesting. Moreover, deep learning models could be used to improve the classification results.

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