Designing a New Data Collection Approach

by

Marat Isteleyev

Submitted to the Department of Computer Science
in partial fulfillment of the requirements for the degree of

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Abstract

Building a quick, efficient and cheap cough classification tool is a very challenging task. It requires a well-thought and rigorous approach. One of the main take-outs behind this tool would be a carefully collected dataset which can serve as a golden high-quality baseline for building an accurate machine learning model.

This study intends to build a new data collection tool and analyze the collected dataset in order to be able to differentiate between various types of cough audio signals. There are very limited efforts that aimed to create a high reliability cough audio signals dataset that is quality controlled by the healthcare professionals. The current dataset contains eight types of coughs plus an additional 'other' type. The primary goal is to design and build a new data collection approach for the Cough Analyzer application and secondly to conduct a data analysis of the collected dataset which contains 1100+ entries to date submitted by the people from around the world.

Thesis Supervisor: Martin Lukac
Title: Associate Professor

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Chapter 1

Introduction

COVID-19 pandemic had a catastrophic impact globally in 2020-2021. It is an infectious disease that is caused by a SARS-CoV-2 type of coronavirus. While the majority of infected are believed to experience it in mild to moderate extent, there is still a large group of people that fall into a vulnerable category. Cough is a common symptom of a person with COVID-19 and is a major evidence of considerable disbalance in a human body overall. This thesis focuses on implementing a new data collection approach that would contribute to building a machine learning based cough audio signal classifier that differentiates eight types of cough signals collected from adult subjects with an additional 'other' type. The cough types are healthy/forced, asthma, COVID-19, allergy, pneumonia/bronchitis, tuberculosis, cancer, cardio and 'other'. The machine learning model is to exploit the Mel-Frequency Cepstral Coefficients and Constant-Q Cepstral Coefficients as feature maps that are extracted from the dataset of labeled audio signals. The findings should potentially improve the accuracy of current real-time cough audio processing models and contribute to the general knowledge base on respiratory diseases.

Cough is believed to be the foremost symptom of a common cold, however it is also accompanied with numerous respiratory diseases like asthma, COVID-19, etc. It is an extremely often overlooked symptom for many high-risk diseases. Despite the fact that many academic organizations admit that cough diagnosis is of crucial importance [18, 20, 14], there is still no commonly accepted standard how to optimally

diagnose one [2]. Cough is an act that involves 3 phases. It starts with an inspiratory phase, than transforms into expiratory effort against a closed glottis and concludes with an expiratory airflow against an open glottis (See Fig. 1-1).

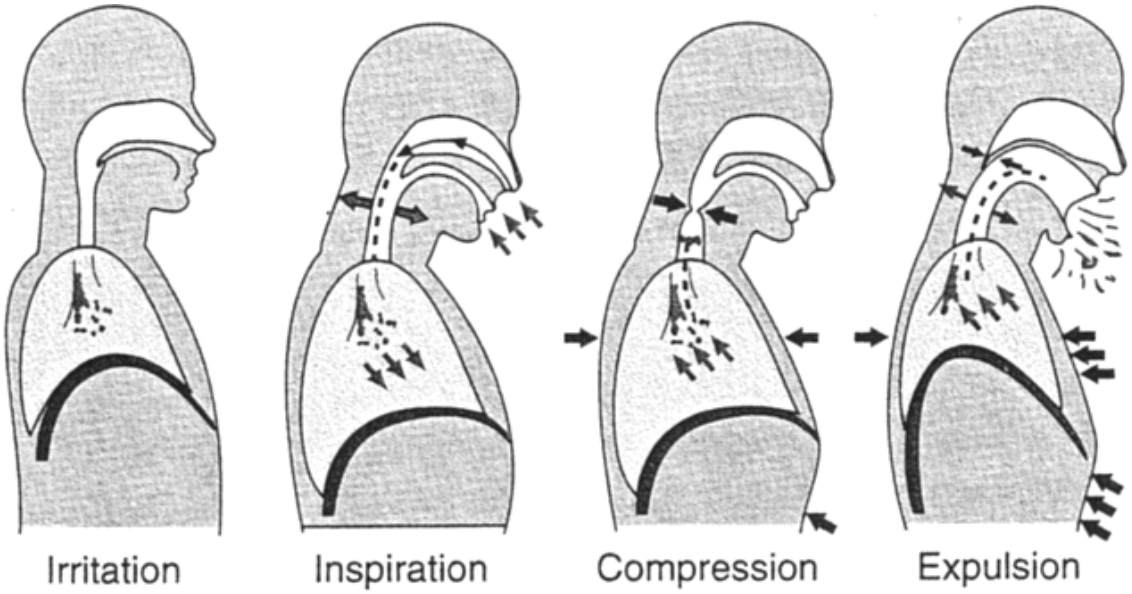


Figure 1-1: Cough phases [12]

The last phase is typically accompanied by what is called a cough sound (See Fig. 1-2). Several additional partial glottis closures cause extra voiced sounds, namely a cough sequence.

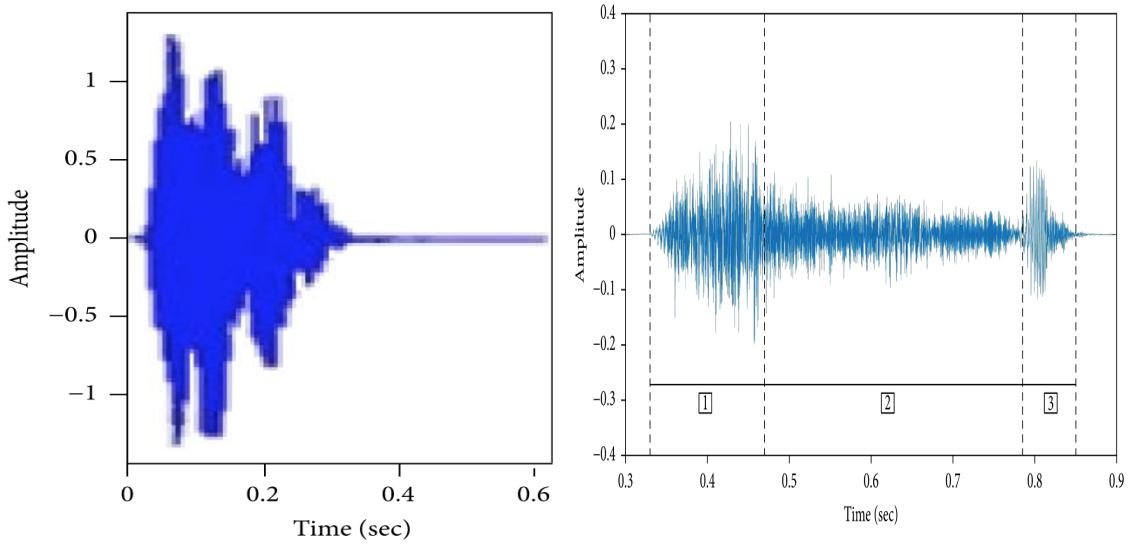


Figure 1-2: Single cough audio signal [26] (left) and Cough phases [26] (right)

There are three main approaches that have been introduced so far which help to monitor human coughs. The first one includes an airflow measurement at the mouth to extract the flow dynamics of cough [13, 23]. This approach proved itself highly inconvenient, since it is difficult to integrate in the normal environment [22]. The next one relies upon registering the chest movement signature. It also was not adopted due to the requirement of continuous control from the researchers. The last and the most up-to-date one is more comprehensive due to the evolution of technology. It involves the analysis of cough sounds.

Chapter 2

Background

Detection of cough has been under research and development since 1950s [7]. Table 2.1 offers a summary of the relevant research on algorithms for automatic cough detection.

Most of the mentioned approaches depend on extraction of features. In traditional machine learning, feature extraction is normally handcrafted with the intention of reducing the size of data, which is important for cough prediction [5]. Following that, the determined characteristics are used as the algorithm's input to train and make it possible to learn a pattern represented in the data, e.g. coughs. This has distinct benefits. First of all, less memory is required for condensed representation of data, less power to compute and eventually reduces the probability of overfitting of the model to the samples of training which leads to weak generalization of new samples that are unseen. However, this comes with the possibility of losing information and restricting the power of representation of the algorithm of learning.

Although some of the most common algorithms for cough detection have been employing microphone signals [6, 27, 16, 3] in neural network architectures, they still rely extensively on the construction of features and they still have a very shallow architecture consisting of 2-4 concealed layers [5]. This can be clarified by the difficulty of obtaining data from actual subjects restricted scaling to a deeper level neural network.

Other approaches have been based on computationally efficient solutions that

Author	Recording Device	Algorithm	Subjects (Coughs)	Cough Type	Sensitivity	Specificity
Coyle et al. 2005 (LifeShirt) [9]	Contact Mic. + Sensor Array	no details	8 (3645)	Reflex	78.10%	99.60%
Barry et al. 2006 (HACC) [6]	Lapel Mic.	PNN	15 (2000)	Reflex	80%	96%
Birring et al. 2008 (LCM) [8]	Lapel Mic.	HMM	15 (1836)	Reflex	91%	99%
Vizel et al. 2010 (PulmoTrack) [28]	Piezoelectric Belt + Lapel & 2 Contact Mic.	no details	12 (no details)	Voluntary	96%	94%
Drugman et al. 2011 [11]	Contact Mic.	ANN	22 (2304)	Voluntary	94.70%	95%
Larson et al. 2011 [15]	Smartphone Built-In Mic.	RF	17 (2558)	Reflex	92%	99.50%
McGuiness et al. 2012 (VitaloJak) [17]	Piezo Sensor	Median Frequency Threshold	10 (no details)	Reflex	97.50%	97.70%
Swarnkar et al. 2013 [27]	Matched Pair Low-Noise Mic.	NN	3 (342)	Reflex	93.44%	94.52%
Liu et al. 2014 [16]	Lapel Mic.	GMM-HMM & GMM-RBM	20 (>2549)	Reflex	90.10%	88.60%
Amrulloh et al. 2015 [3]	Low-Noise Mic.	TDNN	24 (2090)	Reflex	93%	98%
Amoh et al. 2016 [1]	Wearable Sensor / Contact Mic.	CNN & RNN	14 (627)	Voluntary	87.70%	92.70%
Monge-Alvarez et al. 2018 [19]	(2x) Smartphone Built-In Mic.	k-NN	13 (no details)	Reflex	88.51%	99.70%
Bales et al. 2020 [4]	(2x) Public field recordings	CNN	993 (1986)	Reflex	91.9%	86.2%

Table 2.1: State of the art in cough recognition

provide algorithms for cough detection for the smartphone applications [19, 15]. Both of them used traditional machine learning algorithms for learning, such as random forests and k-nearest neighbours. However, their effectiveness has not been tested on multiple devices. Just one work has used two smartphones for recordings where both devices were placed in different locations, i.e. on the table or inside the bag/pocket, and evaluated separately with respect to their position. The proof of concept for cough detection is provided by the broad research in this area [16, 3, 1, 19, 4], as well as the repeatedly recorded strong results over various datasets. It is still open, however, as to whether these detection models generalise well to a wide variety of devices to ensure scalability across the general public.

2.1 Existing datasets

COUGHVID

The COUGHVID dataset [21] is a crowdsourced dataset that contains >20000 cough records. The database was collected between April and September 2020 through a web application created by École Polytechnique Fédérale de Lausanne (EPFL),

Switzerland. COUGHVID also contains 2000 expert-labeled cough recordings. Three pulmonologists manually revised 1000 recordings each, and selected the predefined options like Audio Quality, Type of cough, Audible nasal congestion, etc. It took about 10 hours for experts to label the given data. Each cough recording inside the dataset consists of two identically named files (See Fig. 2-1), but with different extensions. First part is the actual audio signal in either WEBM or OGG formats, whereas second part is the JSON file with accompanying encoded metadata.

4e47612c-6c09-4580-a9b6-2eb6bf2ab40c.webm

```
Input #0, matroska,webm, from '4e47612c-6c09-4580-a9b6-2eb6bf2ab40c.webm':
  Metadata:
    encoder         : Chrome
  Duration: N/A, start: 0.000000, bitrate: N/A
    Stream #0:0(eng): Audio: opus, 48000 Hz, mono, fltp (default)
```

4e47612c-6c09-4580-a9b6-2eb6bf2ab40c.json


```
{
    "datetime": "2020-04-10T10:30:31.576207+00:00",
    "cough_detected": "0.9466",
    "age": "50",
    "gender": "male",
    "respiratory_condition": "True",
    "fever_muscle_pain": "False",
    "status": "COVID-19",
    "expert_labels_1": {
        "quality": "ok",
        "cough_type": "dry",
        "dyspnea": "False",
        "wheezing": "False",
        "stridor": "False",
        "choking": "False",
        "congestion": "False",
        "nothing": "True",
        "diagnosis": "COVID-19",
        "severity": "mild"
    }
}
```


Figure 2-1: COUGHVID data recording

COSWARA

The COSWARA project [25] by Indian Institute of Science (IISc) in Bangalore is focused on building a crowdsourced dataset too. Currently, as of July 7, 2021, it contains 1986 entries. Interesting point is that on August 7, 2020 the project had 941 entries meaning that the dataset nearly doubled in size since then. The dataset contains 34 fields of information such as gender, age, date, location, covid status, smoking status, etc (see Fig. 2-2).

The COSWARA project general strategy consists of three stages: Data collection followed by Model construction, and implementation of a Diagnostic Tool stage. Thus,

	id	a	covid_status	ep	g	l_c	l_l	l_s	rU	smoker
2	iV3Db6t1T8b7c5HQY2TwxIhjbzD3	28	healthy	y	male	India	Anantapur	Andhra Pradesh	n	
3	AxuYWBN0jFVLINCBqIW5aZmGCdu1	25	healthy	y	male	India	BENGALURU URBAN	Karnataka	n	True
4	C5elsssb9GSkaAgIfsHMHeR6fSh1	28	healthy	y	female	United States	Pittsburgh	Pennsylvania	n	
5	YjbEAECMBIaZKyfqOvWy5DDImUb2	26	healthy	y	male	India	Bangalore	Karnataka	n	
6	aGOvk4ji0cVqlzCs1jHnzlw2UEy2	32	healthy	y	male	India	Nalanda	Bihar	n	
7	yWp5tMRFDzbbeEe2csKNd909fqh1	33	no_resp_illness_exposed	y	male	United States	Tucson	Arizona	n	
8	rB5oGtrGYZR5uJUXEaDYrrredz13	23	healthy	y	male	France		Aisne	y	
9	OW5RTM4WXPawz0QLpsfjsl4FqM22	33	healthy	y	male	India	Hyderabad	Telangana	n	
10	lF4uHVWCoBPlnxvapmUJ4ROtYV73	26	healthy	y	female	India	Nagpur	Maharashtra	n	
11	LYJToDRYDZfpjBuNC6YkUcphr0q1	27	healthy	y	male	India	Bangalore	Karnataka	n	True
12	vgalxe6N8uQfcnstW4gWet53Amt2	45	resp_illness_not_identified	y	male	Canada	Vancouver	British Columbia	n	
13	pOZwqBg4NsVYWASmwwhXFq4UlpC2	35	healthy	y	male	India	Sector 15	Chandigarh	n	
14	aB7zSIAFW7bCmQC7lBUWFjNncTF3	36	healthy	y	female	United States		Kansas	n	
15	GzhrTQhWHSTwvweRKx2x1Uh4wx52	35	healthy	y	male	India	Bangalore	Karnataka	n	

Figure 2-2: COSWARA metadata table

it makes COSWARA projects' strategy and objectives very similar to what Cough Analyzer Project is heading towards and implementing at the moment.

Cough Analyzer

Cough Analyzer project by Nazarbayev University [10] aims to build a database using a mobile app and create an AI-based system for detecting, recognizing, and analyzing human cough sounds. Another goal is to improve telemedicine and connect app users to healthcare professionals regarding their concerns related to infectious and respiratory diseases. At this moment, the Cough Analyzer database contains 1100+ entries and the data collection is progressing. Although the COSWARA project goals closely intersect with the current project, the Cough Analyzer project aims to be different by providing a local expert-annotated human cough recordings dataset particularly from the Central Asian region, thus, it will contribute to the existing available datasets list in this sense. This thesis study is performed as part of the Cough Analyzer project.

Chapter 3

Used Technology

This section describes the main backend technology stack that was used in order to build and support the Cough Analyzer mobile and web apps.

3.1 Flutter

Flutter is a new mobile app development framework that was first released in mid 2017 by Google, however in started to gain more public interest very recently only. It has Google's support and hence the software development community started to trust it more as time passed. Software developers who use Flutter are pushed to write the code in Dart programming language, which is being compiled into native ARM by Flutter runtime engine. Flutter framework provides developers with two types of widgets that are responsible for each platform: Material design widget for Android and Cupertino widget for iOS apps.

3.2 Firebase

Firebase is a platform that is also provided by Google Inc. with a motivation to help creating and hosting mobile and web applications in the cloud. It helps developers to build real-time applications and synchronize data across the various devices. It provides hosting and support services for database systems and continuous functioning

of various application scripts within the platform. Firebase contains such features as Firebase SDK, Firebase RestApi, Admin SDK, Firebase Cloud Messaging and etc. It offers a secure authentication procedure with a list of multiple sign-in providers.

3.2.1 Cloud Firestore

One of the key technological toolsets that Firebase provides is Cloud Firestore. It is a NoSQL database that provides offline-support and is managed (and scaled) for developers by Google. It is a fast and reliable document-based cloud storage that securely interacts with mobile, web and server applications. It allows to store files, documents that are organized in collections, such as human cough records and attach an accompanying metadata information. Google Firebase is also responsible for storing user credentials and other information, as well as any type of account activity.

Chapter 4

System Design and Architecture

This section describes the general architecture of the data collections tool that is designed according to the specifications created by the Cough Analyzer project team.

The measurement of cough sounds became more efficient because of advances in computer technology and the availability of portable digital sound recording devices [28]. In this study the initial system design can be seen in Fig 4-1.

Figure 4-1: Initial high level system design

Fig 4-1 can be separated in 3 main parts: A user, a mobile application, a database. User initiates the participation in the experiment by interacting with either iOS, Android or Web app. Then, the application uses some database at the back-end for storing user data. A very straightforward and effective way. Fig 4-2 however, shows the system design in more details. One can see that Google's Cloud Firestore is selected as the database of choice. And the type of data that the app saves is the actual voice recording with an accompanying Cough Details form.

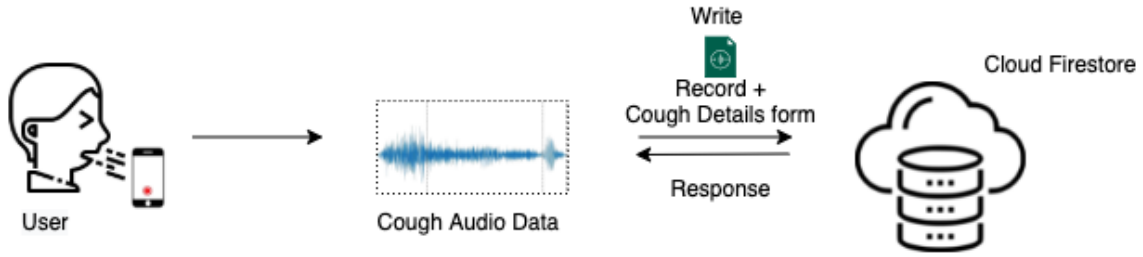


Figure 4-2: Initial high level system design in more details

4.1 Mobile application

The Cough Analyzer project team decided to create a mobile app (Fig.4-3), firstly, to collect cough audio data from users and, secondly, to be able to process the collected data and provide a quick feedback using a machine learning model that would help diagnose the cough audio signal submitted by the user.

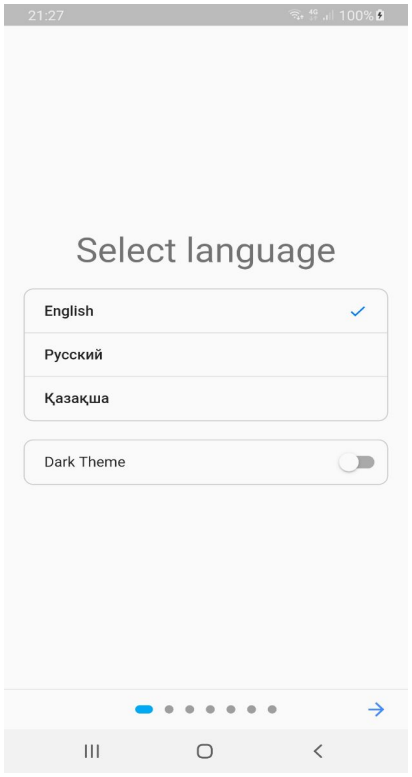


Figure 4-3: Application on Play Store and App Store

The opportunity to provide an immediate response can help someone react accordingly, and also is a very low-cost alternative to a traditional appointment-based doctor-patient approach. For obvious reasons, the application is not planning to claim

the result to be final and official, it aims to become rather a supplementary factor to work as an alarm.

4.2 Web application

The web client is implemented predominantly for the administration processes such as providing or revoking certain users with admin rights, user profiles verification procedure for healthcare professionals, download cough record questionnaire data in bulk, perform visual analysis of the main data using the implemented filters and sorting features. Fig. 4-4 is a snapshot of collected data that is stored in our database and available in the web application.

Filters

City	Country	Gender	Age	Cough	Cough Type	Smoking	Choose your diagnosis	Severity	Time	Accepted
Astana	Kazakhstan	Male	21	Forced	Dry	Nonsmoker	I do not have a diagnosis	Least concern	2021-06-15 23:29	
Astana	Kazakhstan	Male	21	Forced	Dry	Nonsmoker	I do not have a diagnosis	Least concern	2021-06-15 23:10	
Astana	Kazakhstan	Male	21	Forced	Dry	Nonsmoker	I do not have a diagnosis	Least concern	2021-06-15 21:47	
Astana	Kazakhstan	Male	21	Forced	Dry	Nonsmoker	I do not have a diagnosis	Least concern	2021-06-15 21:29	
Astana	Kazakhstan	Male	31	Forced	Dry	Nonsmoker	I do not have a diagnosis	Least concern	2021-06-15 18:28	
Astana	Kazakhstan	Male	31	Forced	Dry	Nonsmoker	I do not have a diagnosis	Least concern	2021-06-15 13:15	
mumbai	Australia	Male	28	Forced	Wet (productive)	Nonsmoker	I do not have a diagnosis	Least concern	2021-06-15 11:01	
mumbai	Australia	Female	25	Forced	Dry	Nonsmoker	Allergies	Doctor prescribed medicine	2021-06-15 10:56	
mumbai	Australia	Female	25	Forced	Dry	Nonsmoker	Other	Doctor required test or imaging	2021-06-15 10:53	
Brisbane	Australia	Female	22	Spontaneous	Dry	Smoker	Other	Least concern	2021-06-14 21:25	

Figure 4-4: Snapshot of collected data

Chapter 5

Remote Data Collection

It is commonly known that remote data collection techniques have their own advantages and disadvantages. For instance, a mobile application that anyone can download and submit their own data through seems a very convenient approach to collect the required data. However, there exist many constraints and pitfalls about this method. First of all, it requires mobile users to have certain levels of digital literacy in order to be able to figure out how to use the app. Secondly, even if the digital literacy is sufficient, another difficulty is how to motivate mobile users to join the experiment by installing the app and submitting their data. For that, a better app interface needs to be developed with data security and anonymity requirements in head. In addition, this type of data collection approach leads to feasibility and acceptability of the final collected data quality. For instance, the issue of background noise levels negatively affect the cough audio signal quality and hence the overall machine learning training process and results. It consequently requires researchers to introduce various data cleaning and audio signal denoising techniques in order to bring the data to the acceptable level.

Various data standards describe how different data types should be collected [24]. The traditional standards generally include data definitions, standardised questions with the consequent responses that should strengthen the data quality. Another concern is the ethical issue of the conducted research. Research ethics introduces requirements the protection of anonymity of the experiment subjects and the publi-

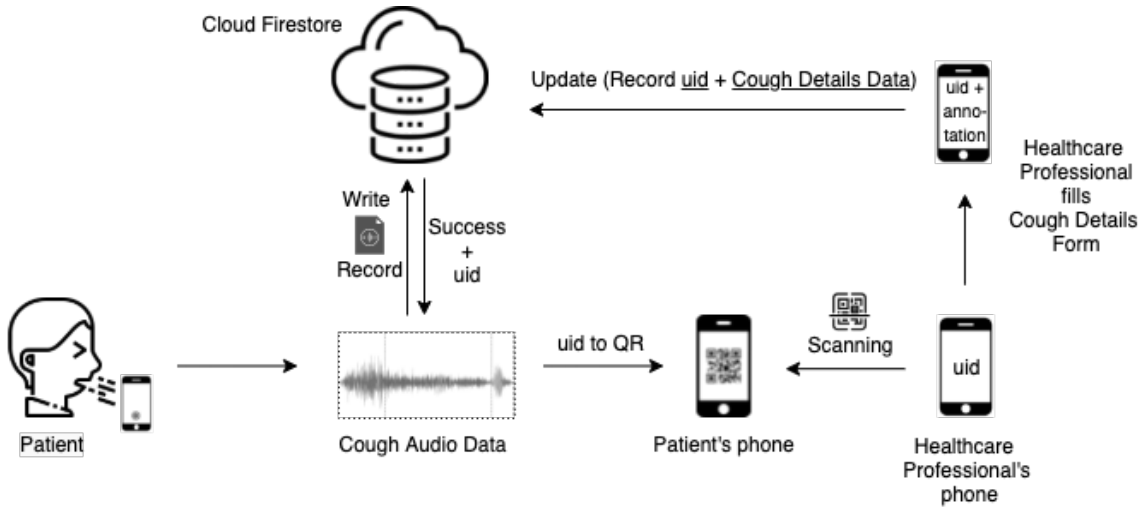


Figure 5-1: Proposed System Design

cation of the information in the public research field. The Cough Analyzer project has a Nazarbayev University Ethical Committee approval to conduct a data collection with a very specific and strict guidelines.

The data acquisition is performed fully via a mobile app which is built on two platforms (iOS and Android). As for the data collection process itself, it has been progressing well over the last twelve months, this is when the app with the main functions to collect the data was built, however it was decided by the team to find solutions to expedite the process since the more data exists for a model to train on, the more accurate predictions it will produce.

5.1 Traditional Approach Procedure

The Cough Analyzer application is localized into four languages. User interaction procedure starts with selecting one of them being followed by five consecutive information screens which briefly explain the application features. After that a user is asked to either login to an existing account or sign up to create a new one. Having authenticated into the app, a user is offered to record own cough. The default recording length is 5 seconds with an additional opportunity to create a longer recording by long-pressing the "Record" button. In the additional tab section, a user can see

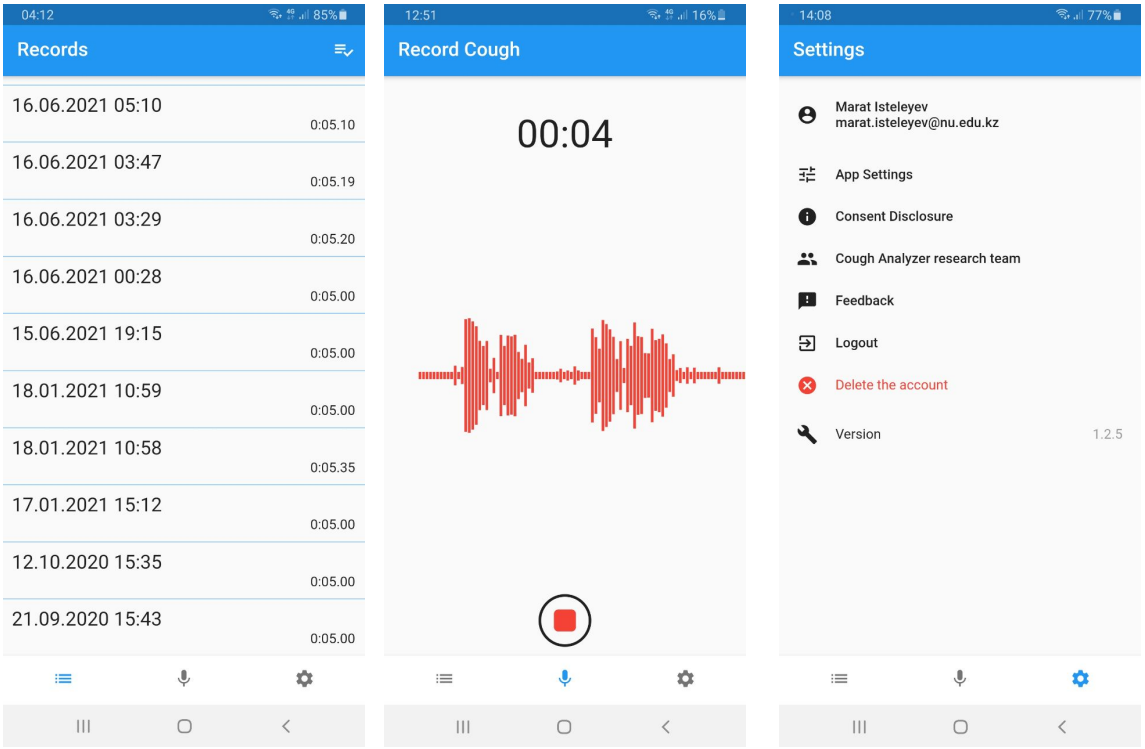


Figure 5-2: A list of previous records, a cough recording process and settings

all previously submitted own records. In the settings menu the application allows to control the app language, change the user interface theme, send feedback to the project team, read consent disclosure, check the app version, delete fully own profile or logout (See Fig.5-2).

5.2 Proposed Method

The proposed method introduces the contactless data collection procedure that involves a user (Patient) and a healthcare professional (HP). A general use case would consist of the following steps.

- HP asks Patient to download the Cough Analyzer app.
- Open application, select Cough-to-QR method and record own cough.
- Show the QR code (Fig. 5.2) to the healthcare professional.

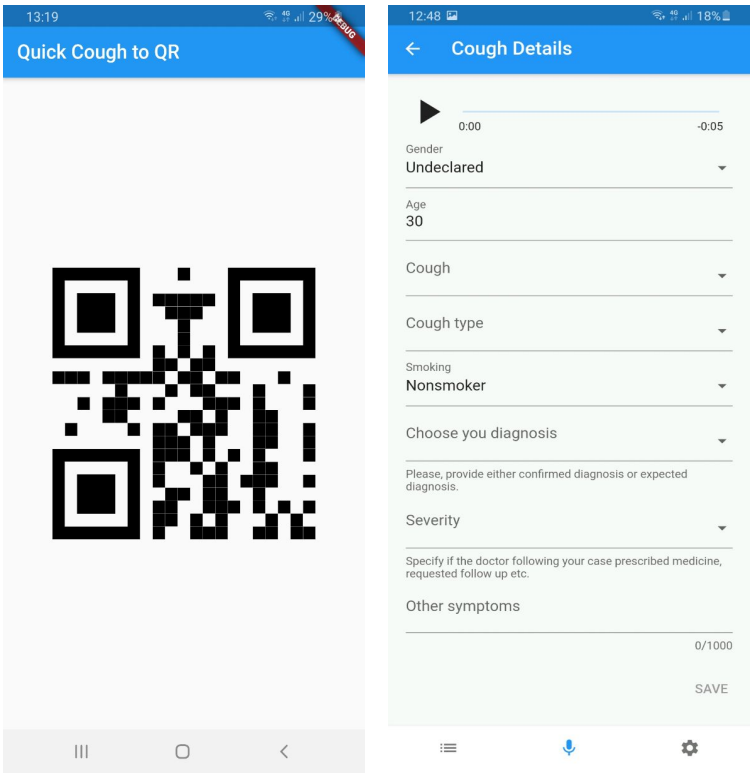


Figure 5-3: Cough to QR screen (left) and Cough Details screen (right)

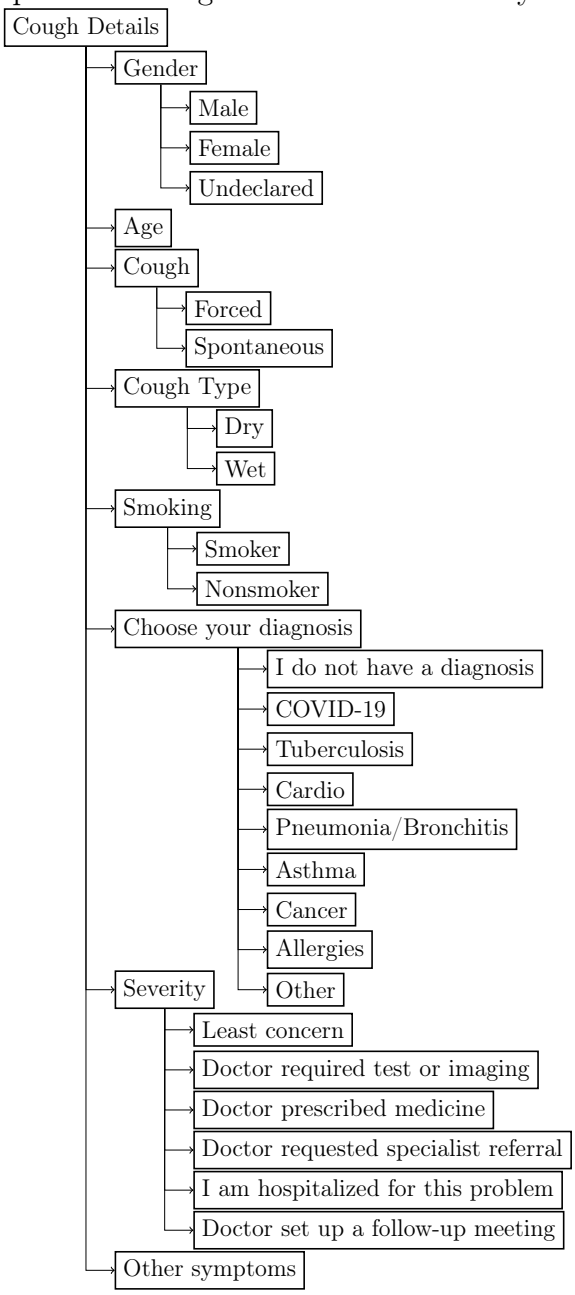
- Healthcare professional scans the QR code with own phone, fills the 'Cough Details form' for the patient and submits the data.

This approach should result in collecting a uniquely annotated cough audio dataset that can serve as a baseline for many audio classification models, existing and new ones.

The main distinctive features of the proposed approach allow patients to contribute their cough records without the need to create a new user account and to make the expert-labelling. The Cough Analyzer project team agrees with [29] that for many patients this constraint plays a big factor. On the other hand, the proposed method does require involvement of a registered healthcare professional. At this stage, the traditional and the newly proposed methods are both combined in the Cough Analyzer application. It is up to the users decision what method to use.

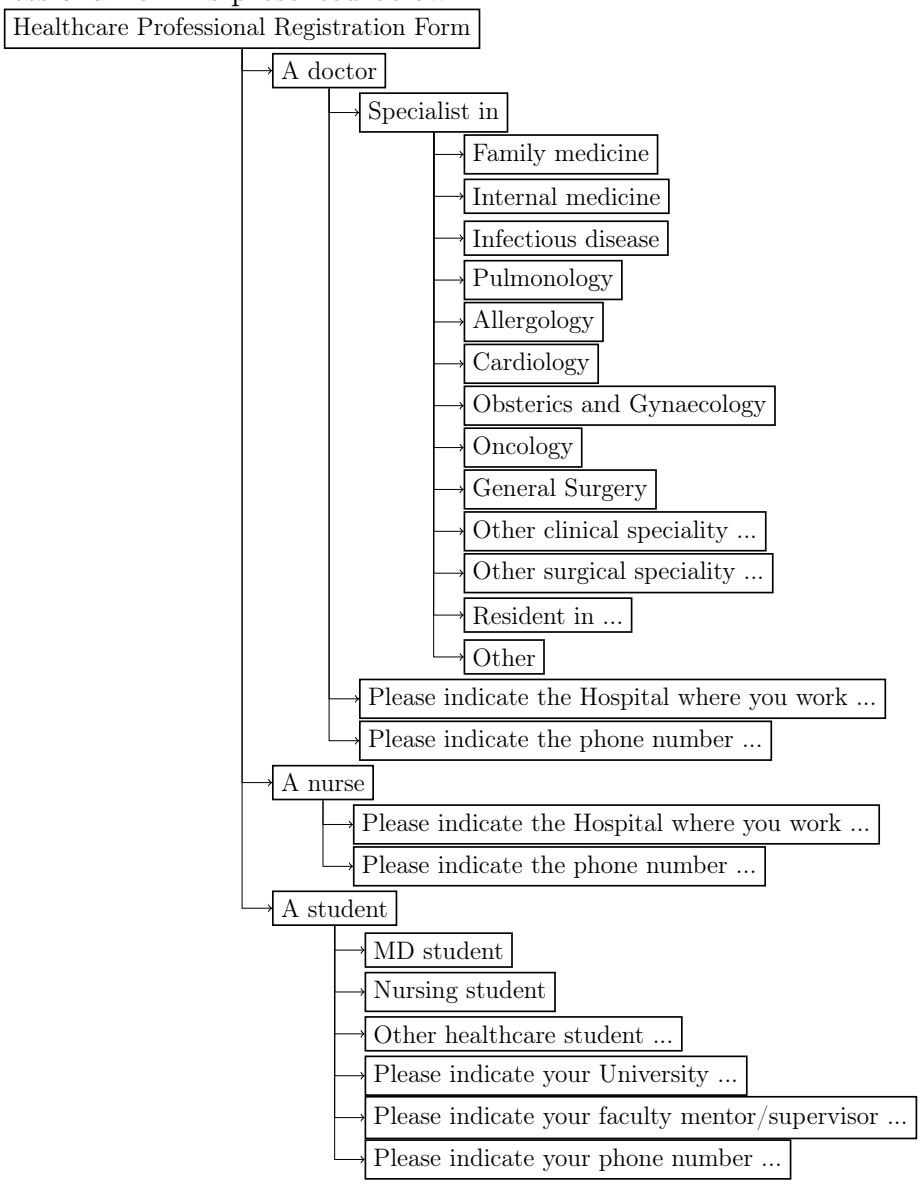
5.2.1 Cough Details form

One of the key points during the data collection process is the Cough Details form (Fig. 5-3) that is being offered to the users. The Cough Details form is identical for both data collection approaches. It serves as a form of data annotation tool which represents their health status. The project team expects all data contributors to complete the Cough Details form honestly and to the best of their knowledge.



5.2.2 Registration of Healthcare Professionals

Cough Analyzer application allows two types of users: a general user and a healthcare professional. A general user is allowed to record, annotate and save own cough audio record. A healthcare professional (HP), on the other hand, is allowed only to scan and annotate patient's cough records, not own. This separation allows data to be stored and divided in two different categories and make future data analysis persistent and reliable. A registration process for a HP is also implemented in the new update. Each registered HP is verified by the Cough Analyzer project manager. A healthcare professional form is presented below:



Chapter 6

Collected Data

To this moment, the collected dataset contains 818 submissions from around the world. Gender representation of the dataset could be improved as the majority of users are males, resulting in 38.6% of male and 60.6% female submissions. Interestingly enough, only less than 1% of people decided not to disclose their gender.

Fig. 6-1 demonstrates that the majority of users (>51%) represent an age group ranging from 18 to 40 years old. 27% of users reported that they are aged 18-30 years old, while 24% are aged 31-40 years old. There is also a good proportion of submissions older than 40 years old: 18.95% aged 41-50 years old, 12.47% aged 51-60 years old and 6.72% are more than 60 years old. There is also a 10% portion of minors (under 18 years old). There should be an effort to recruit larger number of elderly adults for data collection.

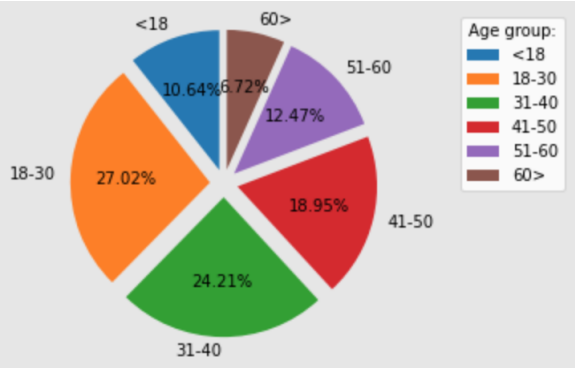


Figure 6-1: Age group

It is important to note that majority of the dataset contributors (3 out of 4 i.e. 76.89%) declared themselves as non-smokers.

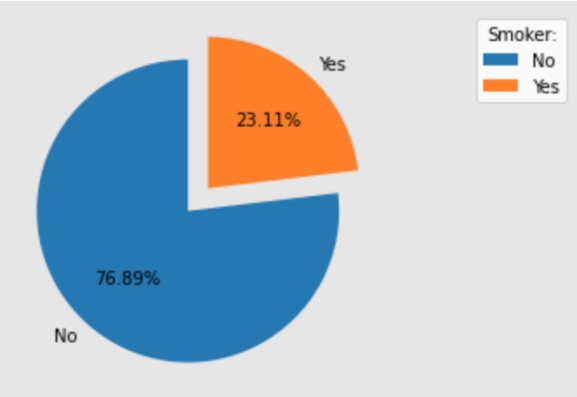


Figure 6-2: Smoking status

From Fig. 6-3 one can notice that nearly 1/3 (29.34%) of the users have no diagnosis at the moment and potentially are willing to get more knowledge about their health status from the cough recording. Majority of the contributors indicated their diagnosis as "Other" which could mean that they are unaware of their diagnosis or prefer not to specify it.

12.35% were diagnozed with COVID-19 at the time of data collection, while there were 7.70% of people with asthma, 3.42% with pneumonia or bronchitis, and 6.60% had allergy.

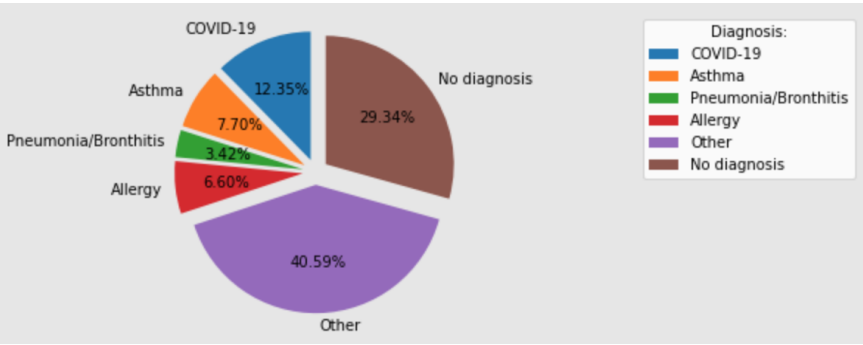


Figure 6-3: User diagnosis

Finally, the dataset contritors were asked to indicate the cough type: wet 'Dry' or 'Wet (Productive)' cough types. Fig. 6-4 presents the proportion of user responses with dry cough constituting $\tilde{7}0\%$ of all data samples. Wet cough was reported to be

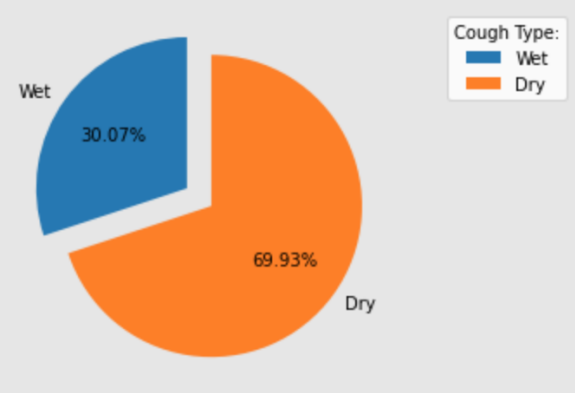


Figure 6-4: Cough Type

the type of cough of $\tilde{3}0\%$ respondents.

Chapter 7

Evaluation

In order to evaluate the proposed data collection tool, it was decided to perform an Experts Review as well as to design and conduct a Usability Test with potential users of the Cough Analyzer application. One of the main goals of these evaluations was to collect and analyze the user experience feedback regarding the data collection approach, its ease of use, convenience and efficiency.

7.1 Experts review

An expert review is a type of evaluation that is used to find usability issues with a product or service. Experts perform the review in which they carefully examine the product or service in search of potential usability concerns. This expert usability evaluation is one of the few approaches used in the user-centered design process that does not involve the end users.

To this end, we conducted in-person interviews with two User Experience (UX) engineers working in industry. The experts were invited for coffee and were given a mobile phone with the Cough Analyzer application installed on it. After each review we complied a list of changes to be made to the data collection tool.

The meetings with two UX experts were held on two different days. The experts were asked to use the application and to identify any usability issues. The reviews were audio recorded for later analysis.

7.1.1 Expert 1

The first UX expert highlighted the appealing and minimalistic design that is easy to understand. Additionally, the expert commented on the fact that it was possible to record the cough by simply clicking the "record" icon without the need to login and sign up. The logo was also complimented on. Signing in with Google account, Apple ID, or email was also appreciated due to the fact that it would speed up the process of data collection.

Then, the expert decided to record the cough without signing in a fast-track fashion. The screen with the recording functionality was also positively perceived with comments regarding the red line that makes the visibility of the system status (i.e. recording in the progress) being clear. However the first issue was upon pressing the stop button with the warning message "Recorded cough is too short". The expert suggested to provide this instructions prior to recording so that the user does not need to cough again, which might result in "unnatural coughing". Therefore, the first suggestion was to *to add instructions that the cough should be at least 3 seconds long.*

Second issue was due to the fact that "Wipe the screen" message might be inappropriate when people do not have a tissue next to them. Again, an instruction prior to coughing might help to avoid such situation. To this end, the next suggestion was *to add instructions to prepare a napkin or tissue to wipe the screen after the cough.*

On a similar note, the expert suggested to *display the system status that the cough was collected successfully and to thank the user for their time.*

The next screen displays a QR code to show it to the doctor with an ability to listen to the recording. The comment here was the it was not possible to trim, edit or delete the recording before saving it to a dataset. The expert commented that although it is possible to record the cough all over again, it is not the same as the newly recorded cough might be "unnatural coughing". Therefore, the next suggestion was to *to add edit, trim and delete buttons to be able to modify the recording before saving it in a dataset.*

After that, the expert was given login details to login to a profile with existing records. The expert commented on the fact that there are only three bottom icons that make the application easier to navigate around. The left icon contained records of the recordings sorted by date. The expert clicked on several of them to listen to the recordings and read some details about them (e.g. age, gender, etc.). Next, the expert examined the Settings screen and also felt positive about it. As there were no major issues found, the review was stopped after thanking the expert for his time.

It should be noted that the expert did not use the record feature within the logged in account, therefore missed the form interface.

7.1.2 Expert 2

The second UX expert also appreciated the clean and neat design of the interface with minimum bottom navigation options. This reviewer was able to identify new usability issues with the interface. For example, when the "back" button was pressed at the QR code screen, the recording was not saved with a need to record the cough again. It was suggested to *to have an option to retrieve that unsaved recording.*

This expert suggested *to color the timer to indicate that the 3-seconds minimum duration has not yet passed, when it has passed and when the recording is long enough.*

Similarly to expert 1, this expert was also given a login information to examine the interface. This time, the expert was explicitly asked to record the cough. The first comment was related to the title of the screen and the suggestion was *to rename the title of the screen from Cough Details to "Please fill in the form"* as the form asks for personal information about the user.

The next suggestion was *to populate some of the form's fields with existing account details such as sex, age, and other personal information.* As it was pointed out by the expert, people could use their accounts to record someone else's cough, in that case *such pre-populated details should be editable.*

Again, it was suggested *to provide the options to edit, trim, and delete cough data.* Additionally, the expert suggested *to allow the questions to be left unanswered as well as to decrease the amount of questions as some of these questions might be difficult*

to answer. As the expert was finished with the review, he was thanked and the audio recording was stopped.

7.1.3 Issues and Suggestions by the Experts

The following issues and suggestions were identified by two senior UX experts:

1. to add instructions that the cough should be at least 3 seconds long;
2. to add instructions to prepare a napkin or tissue to wipe the screen after the cough;
3. to display the system status that the cough was collected successfully and to thank the user for their time;
4. to add edit, trim and delete buttons to be able to modify the recording before saving it in a dataset;
5. to have an option to retrieve unsaved recordings when the "back" button is pressed;
6. to color the timer to indicate that a minimum duration of 3 seconds has not yet passed, when it has passed and when the recording is long enough;
7. to rename the title of the screen from Cough Details to "Please fill in the form";
8. to populate some of the form's fields with existing account details such as sex, age, and other personal information;
9. such pre-populated details to be editable;
10. to provide the options to edit, trim, and delete cough data within the Cough Details screen;
11. to allow the questions to be left unanswered as well as to decrease the amount of questions as some of these questions might be difficult to answer.

7.2 Usability testing

To investigate whether the proposed updates in a user interface are efficient, convenient and potentially could contribute to a better data collection, a usability testing was designed in which participants were expected to interact with the application and provide a feedback by filling in the questionnaire using Qualtrix tool or printed paper application. The usability test was designed in a way that would draw meaningful results in terms of people's attitude towards the user interface and its functionality.

In a typical usability testing session, a researcher (called a "facilitator" or a "moderator") asks a participant to perform a task scenario while speaking out loud their thinking process. While the participant completed the task, the researcher observed the participant's behaviour and listened to feedback. The audio was recorded for later analysis.

7.2.1 Participants

The target population of the study were adults residing in Kazakhstan that own smartphones and are used to interact with smartphone applications. There were a total of 9 participants around 22-66 years of age (M = 44.5 years old, Female = 4, Male = 5) recruited by word of mouth. Table 7.1 presents participant's demographics and other characteristics. There were three medical professionals (two GPs and one nurse in retirement), three patients, and three general users. As suggested by guidelines on conducting a user study, a good baseline for the number of subjects is between five and ten participants or when the new usability issues are no longer found. We stopped conducting the user study when the participants started to repeat previously identified issues.

7.2.2 Procedure

The study procedure consisted of two steps: use of a mobile phone application and a questionnaire filled by the subject. Participants were asked to perform one of the three use cases depending on their user type presented in Table 7.2 for general

ID	Age	User type	Sex	City	Lang.	Past COVID-19	Vaccinated
P1	33	Doctor	F	Nur-Sultan	Kaz	+	+
P2	45	Doctor	M	Nur-Sultan	Rus	+	+
P3	65	Nurse	F	Kostanay	Rus	+	+
P4	29	User	F	Atyrau	Kaz	+	-
P5	57	Patient	M	Nur-Sultan	Kaz	+	+
P7	30	Patient	M	Pavlodar	Rus	+	+
P9	22	Patient	M	Nur-Sultan	Rus	+	-
P6	66	User	M	Kostanay	Rus	+	+
P8	54	User	F	Nur-Sultan	Rus	+	+

Table 7.1: Participant's demographics and other characteristics

users, Table 7.3 for patients, and Table 7.4 for medical professionals. To identify the participants' demographic information, they were asked general questions about their background on the COVID-19 and vaccination status. Next, they were asked to use the application. While "patients" could use the application without signing in, "users" had to sign up. During the interaction process, participants were asked to speak out load their thinking process to understand what confuses them. After interacting for about five-ten minutes, the final step of the study comprised a questionnaire with a set of open-ended and Likert-scale questions to identify the participants' attitude and their impressions of the application use.

7.2.3 Test Scenarios and Questionnaire

As mentioned above, the users were firstly asked to select who they associated with: a patient, a medical professional (doctor, medical student, nurse, etc.), or a general user. A user would need to be selected if case they do not associate themselves as a patient (someone being under treatment by a medical doctor) or a medical professional.

If a medical professional was selected, a follow-up question asked if they identified themselves as: a doctor, a nurse, a medical student, academic, or other.

Table 7.2 presents questions for general users, Table 7.3 for patients, and Table 7.4 for medical professionals.

Use case 1:	**Record and submit a cough sound as a general user**
Description:	Create a cough sound via the Cough Analyzer app using the traditional approach (requires to sign up).
Questions:	Please specify if you used the app as a user, a patient or a medical professional?
	How would you describe your overall experience with the app? (1-100)
	Please rate the app according to the following characteristics (1-5): Ease of use, Nice design, Quick and efficient, Helpful
	What did you like the most about using this app?
	What did you like the least?
	What, if anything, surprised you about the experience?
	What, if anything, caused you frustration?
	Have you managed to successfully record your cough sound?
	If no -> Why not? What caused your problems?
	Have you managed to fill in the form?
	If no -> Why not? What caused your problems?
	Based on your experience with the app, how likely are you to use it again?
	Based on your experience with the app, would you recommend it to your friend, family member or colleague?
	How often would you use the app?
	If you would like to share any additional comments or experiences about the app, please enter them below.
	Two final questions to know more about you. What is your age?
	How do you identify?

Table 7.2: List of questions asked during the usability testing.

Use case 2:	**Record and submit a cough sound as a patient**
Description:	Create a cough sound via the Cough Analyzer app using the proposed approach (does not require to sign up).
Questions:	Please specify if you used the app as a user, a patient or a medical professional?
	How would you describe your overall experience with the app? (1-100)
	Please rate the app according to the following characteristics (1-5): Ease of use, Nice design, Quick and efficient, Helpful
	What did you like the most about using this app?
	What did you like the least?
	What, if anything, surprised you about the experience?
	What, if anything, caused you frustration?
	Have you managed to successfully record your cough sound?
	If no -> Why not? What caused your problems?
	Based on your experience with the app, how likely are you to use it again?
	Based on your experience with the app, would you recommend it to your friend, family member or colleague?
	How often would you use the app?
	If you would like to share any additional comments or experiences about the app, please enter them below.
	Two final questions to know more about you. What is your age?
	How do you identify?

Table 7.3: List of questions asked during the usability testing continued.

Use case 3:	**Submit a cough sound as a medical professional**
Description:	Create a cough sound via the Cough Analyzer app using the proposed approach (does not require to sign up).
Questions:	Please specify if you used the app as a user, a patient or a medical professional?
	How would you describe your overall experience with the app? (1-100)
	Please rate the app according to the following characteristics (1-5): Ease of use, Nice design, Quick and efficient, Helpful
	What did you like the most about using this app?
	What did you like the least?
	What, if anything, surprised you about the experience?
	What, if anything, caused you frustration?
	If you are a medical professional, please specify if you are: A nurse, a medical student, a doctor, an academic or other
	Have you managed to successfully scan the patient's QR code?
	If no -> Why not? What caused your problems?
	Have you managed to fill in the form for the patient?
	If no -> Why not? What caused your problems?
	Based on your experience with the app, how likely are you to use it again?
	Based on your experience with the app, would you recommend it to your friend, family member or colleague?
	How often would you use the app?
	If you would like to share any additional comments or experiences about the app, please enter them below.
	Two final questions to know more about you. What is your age?
	How do you identify?

Table 7.4: List of questions asked during the usability testing continued.

7.2.4 Results

Users responded that their satisfaction with the application was rated at 77.5% on average. 66.67% on average was given by the medical professionals, while 83% and 85% were given by the patients and users respectively.

The next question was to rate the application's ease of use, design, speed and efficiency, and helpfulness. Figure 7-1 presents these results. The mean rating for ease of use was 3.67 out of 5. Medical professionals rated the application slightly less than other user types. An average score of 3.44 was given for the design of the application. Again, medical professionals gave a slightly worse rating (only 3.0 in comparison to 3.67 given by the other two user groups). The score for the application's speed and efficiency was 3.67 on average with patients giving it the highest score of 4.0 on average. Finally, the helpfulness of the application was rated at 3.33 score with the same trend of medical professionals giving it the lowest rating.

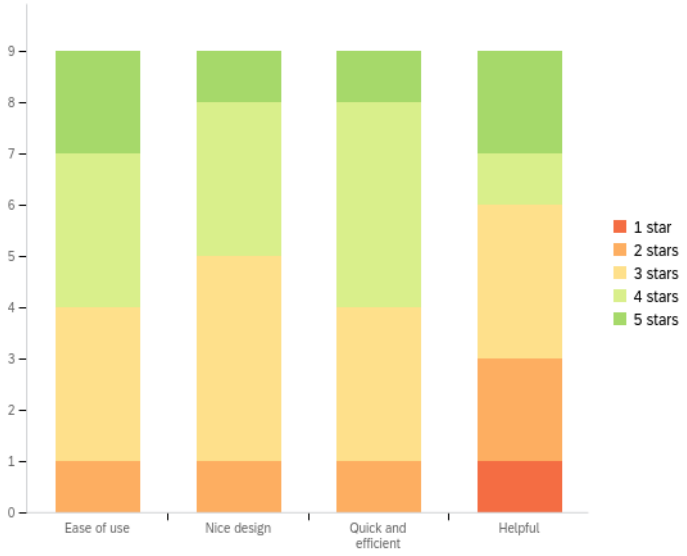


Figure 7-1: Ease of use, Design, Speed and Efficiency, and Helpfulness of the Cough Analyzer

When asked to identify what the users liked the most about the application, most users mentioned its simplicity and fast process of cough recording. Some other comments included the use of smartphone application without the need to have an additional medical device.

When asked to identify what the users liked the least about the application, the users mentioned that the signing up was inconveniently done using email address instead of a simpler phone number-based registration. Additionally, people commented on the need to create a complex password with a warning being too small. That was inconvenient for most users. Although, people were given a mobile to use an already installed application, people still thought about the need to download the application to their phones which was not perceived very well. Small font and small buttons were a common design issue for the older user group.

When asked to identify what surprised the users about the experience, people mentioned the need to sign up with the email address as most government and banking applications in Kazakhstan use phone number for registration. Additionally, people commented on the fact that coughing on the phone was surprising to them. One user got very excited about the project application, in particular mentioning that it is being developed in Kazakhstan and could be used by the doctors on daily basis. One user mentioned that surprisingly difficult questions about the cough details which left her wondering about the need to learn the cough types.

When asked to identify what caused their frustration, people mentioned the need to fill in the application form every time the cough sample is recorded. Similarly to previous comments, the need for registration using email and creating a complex password caused the main frustration. One user also mentioned that the application did not show if the user was healthy or not. Older user was also confused on what to press which caused her some frustration.

When patients were asked if they were able to fill in the form on their own, one patient said yes, while two patients said that they needed a help of the researcher.

When medical professionals were asked if they managed to scan the patient's code, two of them answered yes while one medical professional used the help of the researcher for that. Similarly, two medical professions were able to fill in the form for the patients, while one medical professional responded that some questions were left unanswered as the word "forced" cough was not clear.

Fig. 7-2 displays the answers to the question if the users would use the application

again with most users and patients answering that they are very likely to use it again. Most medical professionals responded that they are slightly likely to do so in the future.

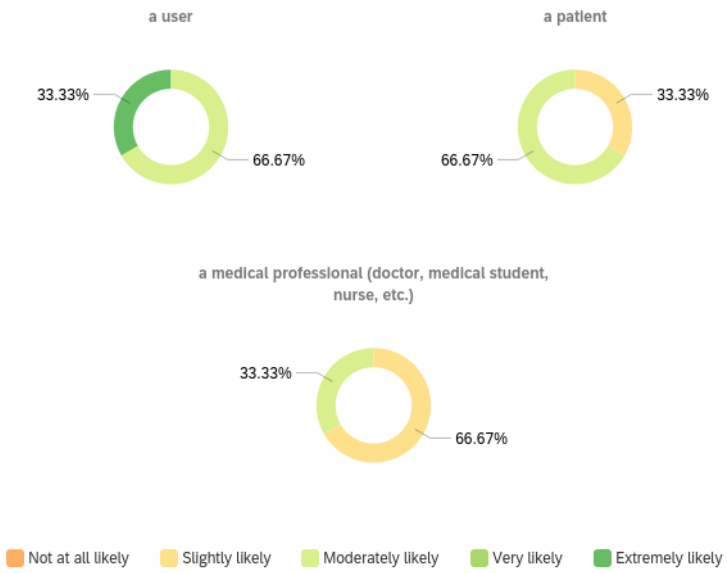


Figure 7-2: Based on your experience with the app, how likely are you to use it again?

Fig. 7-3 displays the answers to the question if the users would recommend the application to their friends, family or colleagues with majority of participants responding that they probably would recommend it. The least enthusiastic were the patients as can be seen from their answers being distributed across 2 to 4 scores.

Fig. 7-4 displays the answers to the question of how often the participants would use the application with most users and patients responding that they would use the application only if they had cough. Medical professionals responded that they would use the application on daily or weekly basis.

Finally, participants could leave their comments and general feedback at the end of the questionnaire with comments thanking for the interesting experience and wishing to test an updated version of the application in the future.

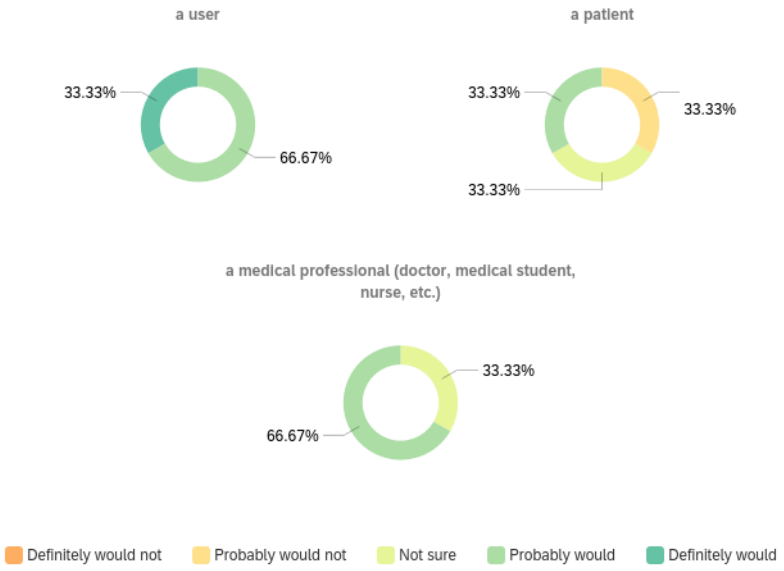


Figure 7-3: Based on your experience with the app, would you recommend it to your friend, family member or colleague?

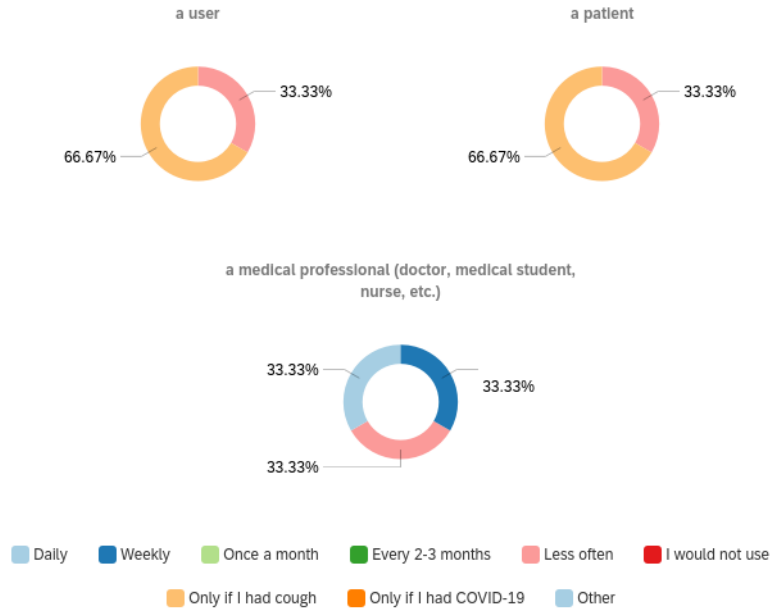


Figure 7-4: How often would you use the app?

7.2.5 Issues and Suggestions by the Users

While most users were successfully able to use the application and record their coughs, there were a number of identified issues with suggestions for improvement:

1. the font in red was too small to read during signing up process ("Password must

be at least eight characters long and contain at least one uppercase letter, one lowercase letter and one number or special character"). It was suggested to increase the font.

2. absence of email address made it impossible to sign up. It was suggested to allow signing up using a phone number.

3. email verification was sent in English (no Russian or Kazakh translations were provided). It was suggested to sent this email in three languages or a selected language.

4. there were comments that some icons were not easy to understand and it suggested to work a bit more on the design of the application.

5. the need for the complex password made it time-consuming to register. The suggestion was to simplify this step.

6. the need to install the application on their smartphones. It was suggested to provide a web-based version of the application to use it without installing it on their phones.

7. cough details were too time-consuming to enter. On the other hand, a medical professional suggested to add some questions on the temperature and saturation.

8. the need to enter personal details (e.g. sex, age) when entering details for the cough when they could be simply pre-populated from the previously submitted information.

Chapter 8

Conclusion

This thesis project is conducted within the Cough Analyzer project funded by Nazarbayev University. As the data collection of cough data is often challenging and expensive due to mislabeled submissions and incorrectly inserted details, the main focus of this thesis work is to design a new data collection approach in order to build a reliable collection of human cough audio records. The term 'reliable dataset' is proposed to indicate that the data is collected as a two-way process: natural human coughs are recorded using patients' phones while medical professionals finish the sample record collection using their phones by filling in the accompanying cough details form. The cough samples are linked using QR codes generated at the recording stage for the patients to send or show the codes to the doctors while they scan them to retrieve the record. Additionally, general users could also contribute to the data collection who need to fill in the cough details themselves.

It is expected that this approach will result in building a collection of human cough audio records which can be treated as a baseline dataset for various machine learning models. During the COVID-19 pandemic time, it became extremely important to follow safety measures among individuals while keeping the data collection process alive and reliable.

The core component of the project is the mobile application which is built on two main mobile platforms, Android and iOS. The technology stack of the mobile app is implemented around the Google Firebase platform and Flutter framework.

The evaluation of the application included an expert review by two senior UX researchers and a usability testing performed by nine users who were either medical professionals, patients and general users. The application was positively perceived with people commenting on its nice design, speed and ease of use, however several usability issues were identified by experts as well as by the end users.

The future work will include integrating the proposed suggestions in order to improve the application's usability as well as the continuation of the data collection process, building a robust and accurate machine learning model and integration of this model into the app ecosystem.

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