Sleep Disease Detection using Machine Learning and Sound Processing

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1 Introduction

In our current days, the healthcare industry is massively improved by technology and the various innovative digital solutions that are appearing every day. Nowadays, because of the fast advancement of technology, there is better and more accessible treatment for a lot of diseases and more efficient care for sick people. Unfortunately, this isn't the case for most sleep diseases even though the process of finding the best diagnosis is a tedious task for most doctors that may take as long as a few days. Also, the task of diagnosing someone with a sleep disease is quite hard since a lot of the population doesn't even know they are suffering from a specific disease therefore, given everything said, we believe that the medical world is in dire need of our help.

a Project description

With enough resources and great volumes of samples that can be processed by automatic systems we can ease the doctors' efforts and help people to detect a disease way faster. Our system will be based on a human-computer collaboration centered on the patient's well-being: the systems process the data and provide a well-documented outcome such as "This patient may have the disease X according to the samples ..." while the medics assess the correctness of the outcome and make any further decisions.

b Motivation

The motivation behind our system is to help the medical field and boost the organizational side of this industry. Machine learning and sound processing could easily reduce the time doctors use for diagnosing the disease, improve the quality of the outcome and take care of more ill patients. The role of our project is to automatize such a repetitive process in order to help the medical world and suffering people.

2 State of the art

As many people started to realize the danger of sleep diseases, many researchers started to look for ways to automate the process of detecting patients that are suffering from sleep diseases. The main idea is to try to detect them based on audio samples uploaded by the patient on an online platform. Some several massive projects, such as **The Tokyo Metropolitan Institute of Medical Science** and **SENSAPNEA**

a The Tokyo Metropolitan Institute of Medical Science[1]

The Tokyo Metropolitan Institute of Medical Science (TMIMS) began its operations in April 2011 as a brand new institute integrating the formerly independently operated three institutes; the Tokyo Metropolitan Institute for Neuroscience, Tokyo Metropolitan Institute of Psychiatry, and Tokyo Metropolitan Institute of Medical Science.

In contemporary society, there is an ongoing shift toward nighttime activities and the shortening of sleep behavior. There have also been reports of qualitative changes in labor and more people are complaining of chronic sleep disorders. The biggest problem with sleep disorders is the difficulty that sleepiness brings to daily life. While nocturnal awakening is also frequently seen to increase with age, there is no effective treatment.

This project seeks to elucidate the pathogenesis of sleep disorders that exhibit symptoms such as oversleeping and sleep fragmentation with the aim of developing new therapeutic drugs and biomarkers for use in the early diagnosis and evaluation of therapeutic efficacy.

Objectives:

- to elucidate the pathogenesis of sleep disorders that exhibit oversleeping and to develop new methods of diagnosis, prevention, and treatment;
- to elucidate the successful foundation of substances that act to stabilize and maintain sleep and to develop new treatments;
- to examine the foundation of arousal controls in cellular and animal models to clarify the conditions for healthy sleep;

b SENSAPNEA[2]

SENSAPNEA is an entrepreneurship project for the development of a simple solution for sleep apnea diagnosis and value-based care. The solution is easy for patients to use in their own homes and is cost-effective for both patients and physicians.

The proposed solution has three components:

- a chin sensor recording mandibular movements, which represent a reliable marker of respiratory efforts;

- a mobile app for patient-operated data recording and dashboard visualization;
- a cloud-based platform for patient data management;

The innovative, simplified sleep apnea diagnostic promises better prevention and management of chronic diseases, at a reduced cost. It also empowers citizens to take charge of their own health with a digitally-enabled platform that involves joint-management with patients.

3 Technologies used

a Models

For deep learning we have used **Keras**, a simple, flexible but powerful library which provides a Python interface for artificial neural networks, acting as an interface for the **TensorFlow** library.

The CNN consists of a model composed of Conv2D, MaxPooling2D, Dense and Dropout layers. As this involves image processing and analyzing, the models have as input data **waveform** of 10 second long events, which represent visualizations of the frequency spectrum of a signal. They require '.wav' files, which are filtered using a 4th-order Butterworth filter with a passband between 100 to 3000 Hz[3], converted to a numpy array and then to waveforms which span 10 seconds using the **librosa** and **matplotlib modules**.

The reasons for choosing Python:

- Platform independence (can run on all platforms)
- Simplicity and consistence (intuitive and easy to learn)
- A great library ecosystem (offers easy to use libraries for data processing, data analysis and deep learning)

b FastAPI

FastAPI is a modern, fast (high-performance), web framework for building APIs with Python 3.7+ based on standard Python type hints.

For the backend to communicate with the ML module developed, FastAPI was used to create a POST method. The syntax used is POST ¡host¿/uploadfile/123/12/file, "file" representing the body (.wav file corresponding to a sound recording of a patient).

The signal read from the file is filtered to reduce unnecessary noise.

After filtering, there are created events corresponding to the first 10 seconds of each minute of recording that are later on given as input for the "predict" method of the ML module.

The predictions are saved along with the start time (in seconds) and the waveform (as Base64 encoding) of the event. Predictions are labeled as such: Healthy, Hypopenea, MixedApnea, and ObstructiveApnea.

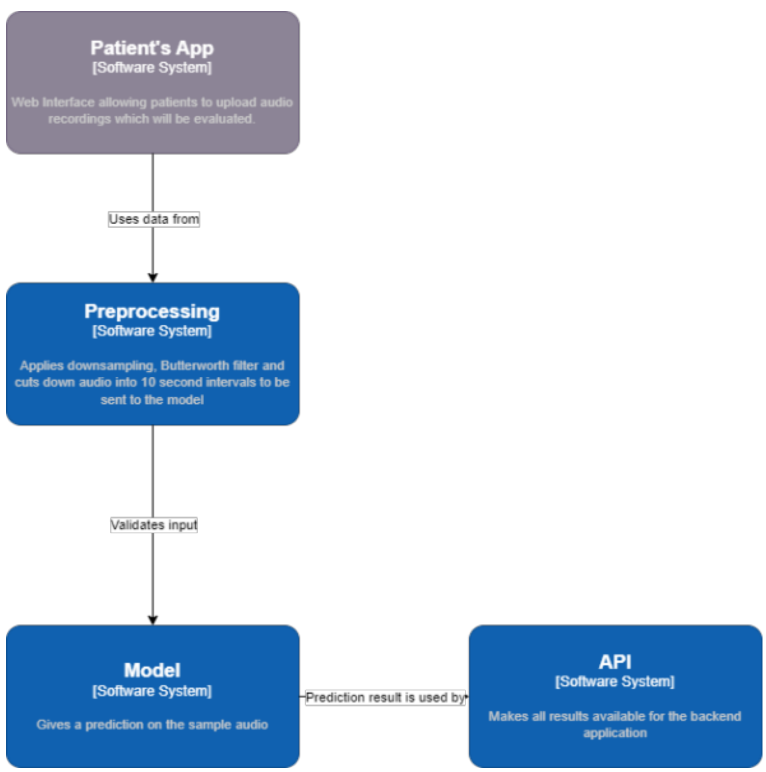
As the computing of events ends, the rate each label appears in the set of events is calculated. If none of them has a higher rate than 75%, the illness is considered unpredicted. Otherwise, it is considered predicted.

The POST method returns a JSON with the following data:

- "predicted" field, that may be either "false" or "true";
- "verdict" field, which may be one of the prediction labels or "null" in case "predicted" is set to "false";
- "events" field, a list with the saved events during the process of sound signal; the list consists of tuples (event name, second, image64); if "predicted" is "true", the "events" is "null";

4 Project structure

a Machine Learning Module



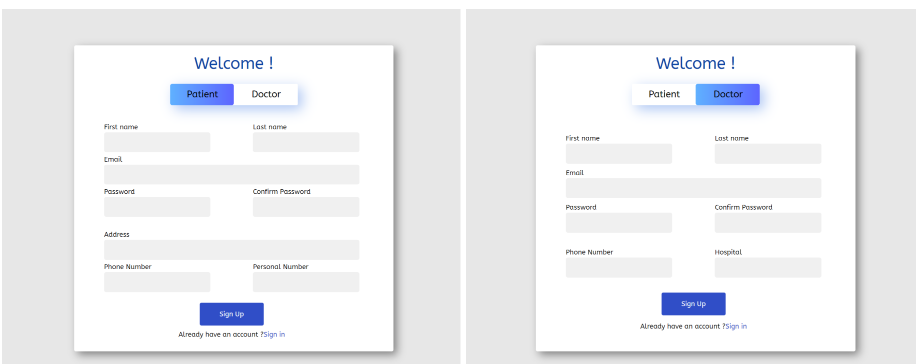
The above diagram shows the components of the Sleep Disease Detection App, focused on the Machine Learning preprocessing and model. The preprocessing module uses data from the patient's application, receiving the audio samples submitted by the user. This is where, through the use of librosa, the audio is preprocessed by cutting down the noise and applying the 4th-order Butterworth Filter[3]. Following this step, the ML Model validates the input and sets a verdict on the patient's health, all while storing an accuracy percentage of the model prediction for each of the 10 second events evaluated. This verdict is then sent to the back-end application through the use of the Python API.

b User Interface

The user application has the landing page with information about the project which provides different options:

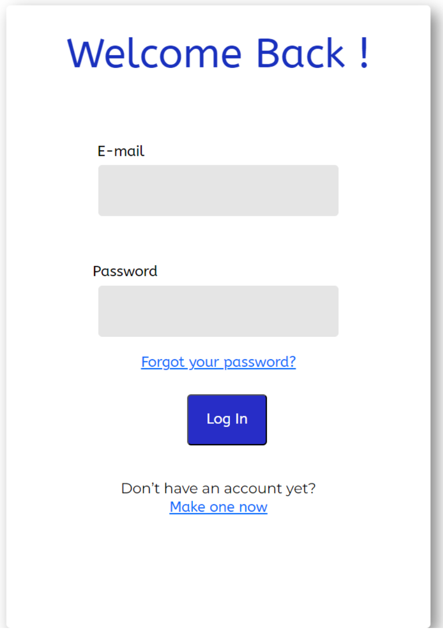
- **Log in -** the user can log in in into his/her account;
- **Sign in -** in case the user doesn't have an account yet, also, the sign-in has, as well, two different options:
  - **Patient -** create a patient account;
  - **Doctor -** create a doctor account;

Depending on the account type of the user logging in, he will be redirected to its corresponding dashboard. During this process, an access token is generated, which will be then stored in the browser's local storage in order to avoid signing up every time the page is accessed.



(a) Patient registration page (b) Doctor registration page

Figure 1: Registration page



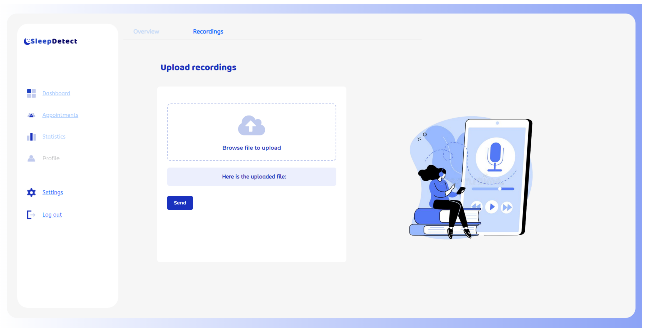
(a) Log-in page

Figure 2: Authentication page

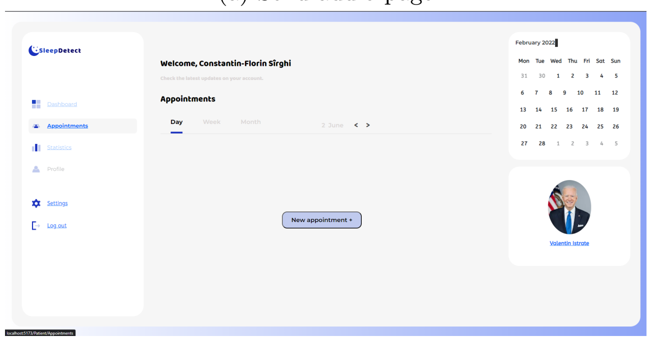
c Patient Interface

The patient dashboard offers the user access to the following pages:

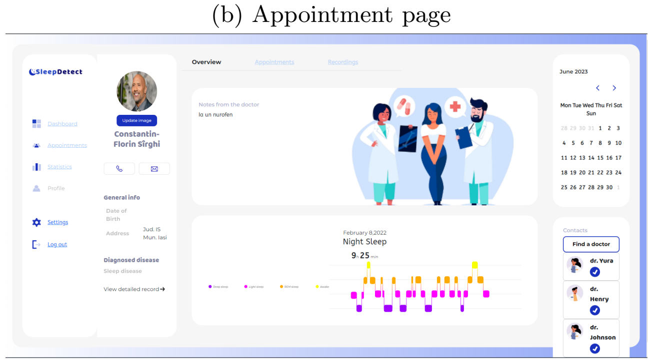
- **Home page -** the patient can see different information about his sleep schedule and profile data and also request to be assigned to a doctor ;
- **Appointment -** the patient can schedule appointments with his/her doctor;
- **Upload audio file -** the patient can upload audio files with his/her sleep and awaits a diagnosis (after the upload, the audio will be analyzed by the ML model and it takes less than 7 seconds);



(a) Send audio page



(b) Appointment page



(c) Profile page

Figure 3: Patient interface

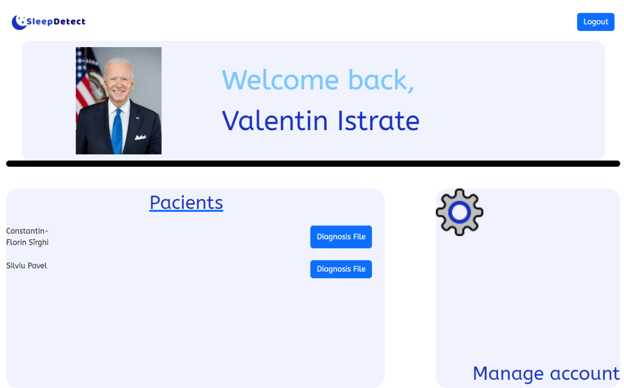
d Doctor Interface

The doctor dashboard offers the user access to the following pages:

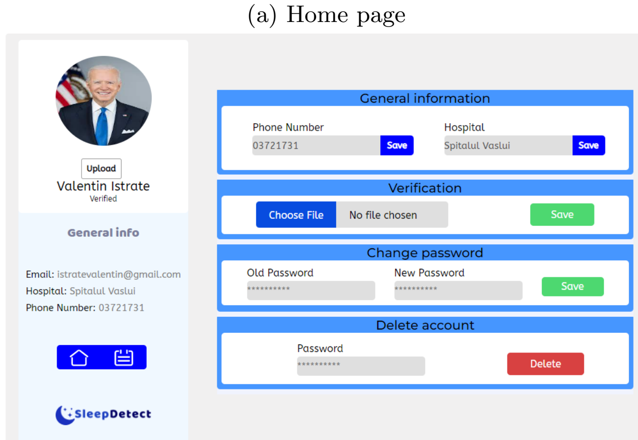
- **Home page**
  - the doctor can send a photo of their diploma to prove their identity;

- the doctor can see all his patients and also access their personal information;
- if a patient receives an inconclusive diagnosis from the ML model the doctor can check it and add decide on the final diagnosis;

- **Profile page -** the doctor can see and edit their profile information;
- **Notes page -** the doctor can add notes for their patients;

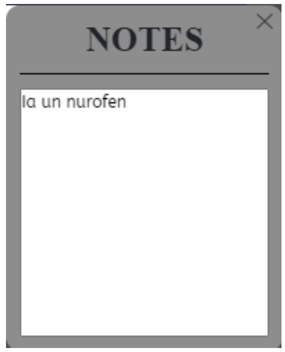


(a) Home page



(b) Profile page

Figure 4: Doctor interface



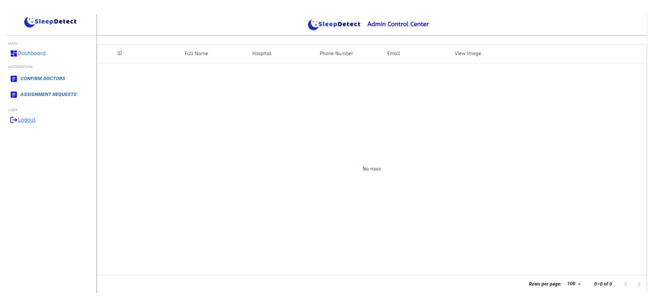
(a) Writing note page

Figure 5: Notes page

e Admin Interface

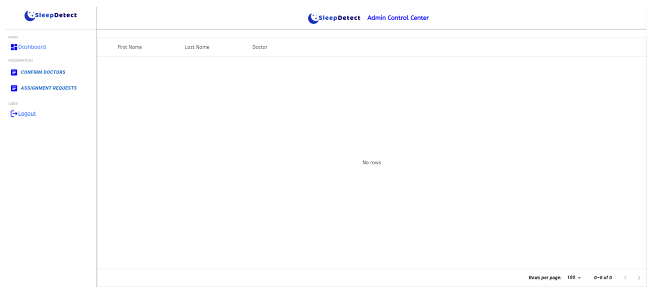
The admin dashboard gives admin users access to the following pages:

- **All users -** the admin can see all the doctors and patients registered on the system and, also, their number;
- **Verify doctor -** the admin can check a doctor's diploma and check if it's valid;
- **Create patient doctor assignment -** the admin can assign a patient (if the patient made an assignment request) to a verified doctor;



(a) Verify doctor page

Figure 6: Admin interface for doctor actions



(a) Assign patient to a doctor page

Figure 7: Admin interface for both users actions

5 The file flow inside ML module

a Training

The dataset used for training consists of multiple edf files comprising polysomnogram signals for 212 patients with rml annotations made by the medical team of Sismanoglio General Hospital of Athens:

- PSG-Audio database

For the training of the Machine Learning model, the audio files in the dataset were read through the use of the **PyEDFlib** library. Then, the events of the 'Tracheal' channel annotated in the rml file were cut down into 10 second intervals and then saved into .png waveform images via the **librosa** library. A waveform is a visual representation of a signal in the form of a wave, indicating the frequency and amplitude of the sound. The events were then grouped into different folders according to the type of disease they represent, according to the rml annotations: Healthy, Hypopnea, Mixed Apnea, Obstructive Apnea. In order to guarantee a balanced dataset, an equal number of each type of event was used during training. The training was done with a batch size of 16 (the number of training examples used in a single iteration) and 50 epochs (the number of complete iterations through the training dataset) based on a split of 60% of the dataset for training, with 20% used for validation and another % used for evaluating the model.

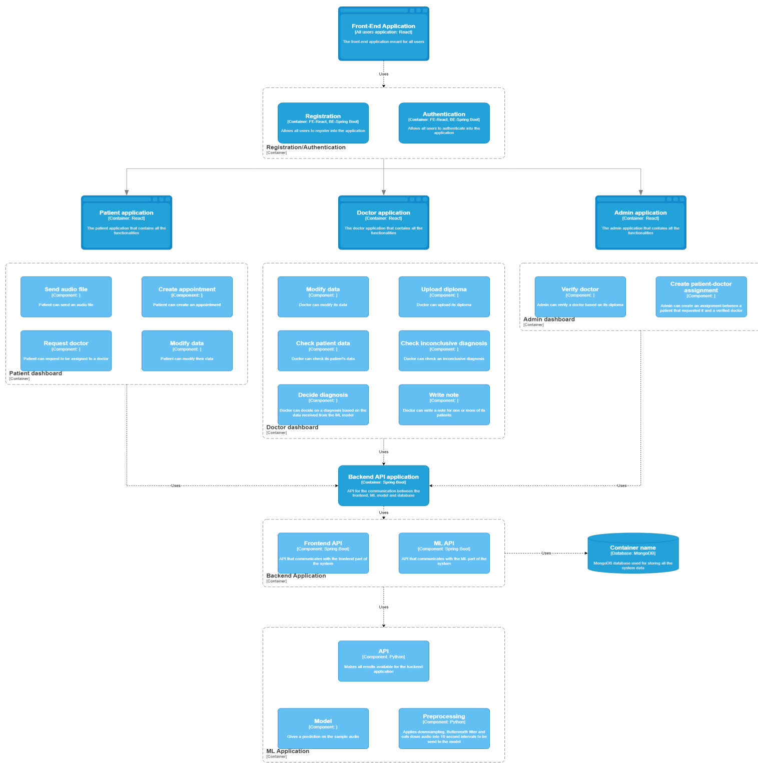
b Prediction

For prediction, the following steps are performed:

- The Python API receives a .wav audio file which is then sent through the preprocessing script.
- The preprocessing script filters the audio and splits it into 10 second intervals that are then turned into .png waveforms

- The model receives the .png waveforms and performs the evaluation
- The result is then sent to the backend of the application and, based on the confidence level of the prediction it is either sent directly to the patient or to an authorized doctor, who will analyze it.

6 Entire project diagram



References

[1] https://www.igakuken.or.jp/english/project/detail/sleep.html

[2] https://eithealth.eu/product-service/sensapnea/

[3] Reyes BA, Reljin N, Chon KH. Tracheal sounds acquisition using smartphones. Sensors (Basel). 2014 Jul 30;14(8):13830-50. doi: 10.3390/s140813830. PMID: 25196108; PMCID: PMC4179049.