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Developing Advanced AI Ecosystems to Enhance Diagnosis and Care for Patients with Depression

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Abstract. Major Depressive Disorder (MDD) has a significant impact on the daily lives of those affected. This concept paper presents a project that aims at addressing MDD challenges through innovative therapy systems. The project consists of two use cases: a multimodal neurofeedback (NFB) therapy and an AI-based virtual therapy assistant (VTA). The multimodal NFB integrates EEG and fNIRS to comprehensively assess brain function. The goal is to develop an open-source NFB toolbox for EEG-fNIRS integration, augmented by the VTA for optimized efficacy. The VTA will be able to collect behavioral data, provide personalized feedback and support MDD patients in their daily lives. This project aims to improve depression treatment by bringing together digital therapy, AI and mobile apps to potentially improve outcomes and accessibility for people living with depression.

Keywords. Depression, virtual therapy assistant, neurofeedback therapy, smartphone, wearables, fNIRS, EEG, AI

1. Introduction

Major Depressive Disorder (MDD) is a prevalent and significant psychiatric disorder with a substantial global economic burden [1,2]. MDD has a strong impact on daily life and is manifested by persistent sadness, decreased joy or interest, feelings of guilt, lack of energy, changes in appetite and sleep patterns, fatigue, and disinterest in everyday

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activities [3]. MDD profoundly affects a person's quality of life, social and emotional functioning, and ability to work. Several factors may contribute to the risk and outcome of MDD, including genetic predisposition, social and environmental factors, demographics, socioeconomic status, neighborhood conditions, socio-environmental events, and lifestyle factors [1]. Individuals with MDD are 20 times more likely to die from suicide than the general population, and approximately 50% of all suicides worldwide occur during depressive episodes [4,1]. The World Health Organization has ranked MDD as the third leading cause of disease burden since 2008 and predicts that by 2030 MDD will be the leading cause [2]. Current treatments of MDD mainly include pharmacotherapeutic and/or psychotherapeutic treatments [1,5]. However, these treatments have several limitations. While psychotherapy is beneficial for many patients, it is not accessible to everyone due to lack of time, limited availability, and cost barriers [6,1]. On the other hand, pharmacotherapeutic treatment often leads to undesirable side effects and requires close monitoring. In addition, a significant proportion of patients do not respond adequately to conventional pharmacotherapy [5]. Finally, the high costs associated with these treatments add significantly to the overall cost of treating depression. Therefore, there is an urgent need to develop further cost-effective therapeutic approaches with minimal side effects.

To address these challenges, the project ***DAIsy - Developing AI ecosystems improving diagnosis and care of mental diseases*** (https://daisy-projekt.eu/) funded by the German Federal Ministry of Education and Research (reference: 01IS22085E), aims to develop new and innovative therapy systems to improve the monitoring and care of patients with MDD. The project focuses on two specific use cases: multimodal neurofeedback (NFB) therapy and an artificial intelligence (AI)-based virtual therapy assistant (VTA).

1.1. Use Case 1: Multimodal Neurofeedback (NFB) System

The overall goal of NFB is that patients learn to self-regulate certain characteristics of their brain activity [7,5]. To achieve this, participants are typically engaged in a task while their neural activity is recorded. Real-time representations of this activity (e.g., visual) are provided to facilitate self-regulation aimed at overcoming specific behavioral or pathological inhibitions [7]. NFB typically uses a single neuroimaging method based on electrophysiological or hemodynamic imaging techniques, to assess and regulate brain activity [7]. Electroencephalography (EEG) captures neuronal electrical activity. It offers a very good temporal resolution paired with the possibility of wireless and mobile measurements, making it a frequent choice for NFB. Limitations of EEG include its limited spatial resolution and susceptibility to motion artifacts (MAs) [8,9]. Hemodynamic imaging methods such as functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) indirectly measure brain activity by monitoring changes in hemodynamics and oxygenation [10]. While fMRI provides high spatial resolution, it is costly, less accessible, and susceptible to MAs [11]. While fNIRS has comparatively lower temporal resolution than EEG and lower spatial resolution compared to fMRI, it offers some advantages, including lower sensitivity to MAs and the ability to measure hemodynamic responses in more natural environments using mobile devices [10]. Multimodal NFB integrating EEG and fNIRS has the potential to

compensate for individual limitations and allow for a more comprehensive assessment of brain function [12]. However, research exploring EEG-fNIRS NFB is currently limited.

The goal of this use case is to develop an open-source NFB toolbox that combines EEG and fNIRS signals for NFB applications. Through validations with healthy individuals and patients, the toolbox will be further refined and optimized over the course of the project to ensure its effectiveness in clinical and research settings. In addition, the project will investigate the integration of the toolbox with a VTA to explore the possibility of improving the therapeutic experience and outcomes for individuals undergoing NFB training. The VTA could help to better tailor NFB therapy to the patient's needs. The integration of fNIRS and EEG along with the incorporation of the VTA represents an innovative direction in NFB research and practice, potentially expanding the reach and impact of NFB applications.

1.2. Use Case 2: Virtual Therapy Assistant (VTA)

Smartphones are growing in popularity in healthcare as they offer the opportunity to facilitate mental health care through portable and convenient applications (apps), solving access problems and encouraging active participation in therapy [13]. Furthermore, the combination of apps and wearables (e.g. smartwatches) could enable continuous monitoring of (bio)markers and signals as well as environmental influences, which could help to overcome traditional assessment limitations and detect signs of depression in real time. This combination could help improve the accuracy and timeliness of mental health monitoring and enable individuals to proactively maintain their well-being [14,15].

The secondary objective of the DAIsy project focuses on the development of a smartphone-based VTA that acts as a supportive companion for individuals undergoing MDD therapy. By analyzing various collected behavioral data, including social interactions, contextual parameters, in situ questionnaires, passive smartphone use, and wearable device information, it aims to explore insightful patterns in patients' behavior and their impact on well-being. The aim is to empower patients through personalized feedback and guidance to learn proactive strategies to improve mental health and to recognize patterns, triggers and connections between behavior and mental states. To this end, the VTA should, among other things, provide content on cognitive behavioral therapy, present psychoeducational material and promote tailor-made coping strategies to support patients in everyday life. It is intended to be a valuable tool that adapts to individual needs and provides support outside of and in addition to therapy sessions. A trustworthy interface design is of particular importance to ensure the trust of patients when passing on personal data. Through this development, the project aims to establish the VTA as a reliable tool to improve the overall therapy experience for the patient and thereby reduce depressive symptoms.

2. Technical Implementation of the DAIsy Therapy System

The DAIsy therapy system will use AI to process complex and diverse data in both use cases. In the multimodal NFB system, an incorporation of AI has the potential to facilitate the combination of fNIRS and EEG signals, thus enabling a more personalized

and tailored therapy approach. The AI in the VTA will be designed to interact with patients and analyze context and sensor data to identify patterns of depression. Techniques such as time series analysis, anomaly detection, and ensemble learning will be used to account for individual variability and heterogeneous data, including

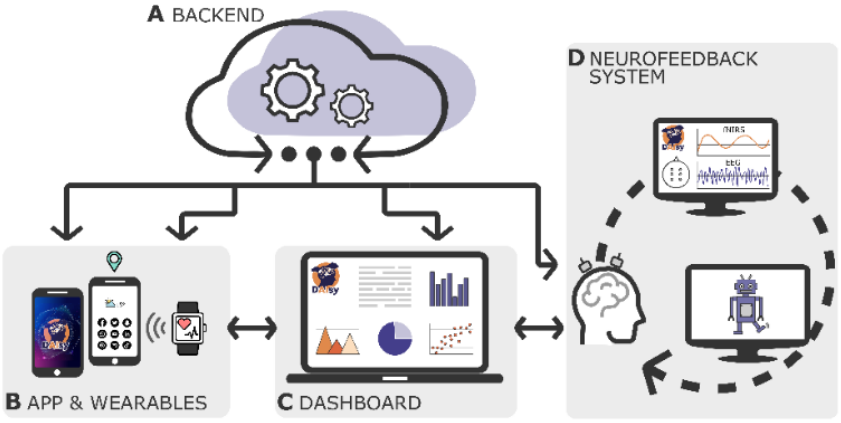

Figure 1. Illustration of the proposed DAIsy therapy system consisting of the system components (A) Backend, (B) App and Wearables, (C) Dashboard, as well as the (D) Neurofeedback System.

sentiment analysis and image analysis.
Technically, the DAIsy therapy system will consist of four interconnected components (cf. Fig. 1):

The DAIsy Backend will leverage a cloud-based architecture for secure data persistence, data and AI analytics. General data protection regulations will ensure privacy and encryption for secure communication and storage.

DAIsy App and Wearables will work together to enable comprehensive depression monitoring. The DAIsy wearable is intended to collect various sensor data for improved monitoring. The app aims to analyze sensor data and contextual parameters to understand experiences and behaviors related to MDD, and to combine data from wearables and smartphone sensors to generate personalized recommendations.

DAIsy Dashboard is a web portal designed to facilitate communication between healthcare providers and patients. It will integrate patient data and thus enable a holistic view of the progress, secure communication and personalized therapy management. To improve decision-making and optimize the treatment plan, an AI-supported decision support system will be integrated.

DAIsy Neurofeedback System can be integrated into the DAIsy dashboard, which could enable more personalized training using fNIRS and EEG data. This allows the system to dynamically adapt the training program to the patient's health data to achieve optimal results. In addition, the system integrates well-known interfaces, including the Lab Streaming Layer, and thus ensures smooth compatibility with different systems and presentation software.

3. Conclusion and Outlook

The DAIsy project aims to improve MDD monitoring and treatment by bringing together innovative therapy systems, AI technology and a user-friendly app for broad therapeutic access, cost-effectiveness and scalability. Through the use of continuous data analysis and personalized feedback, the aim is to improve the well-being and quality of life of people with MDD. Based on performance assessments and evaluations of healthy people and patients, the project will continuously develop the therapy system. Therefore, clinical questionnaires, which are widely used in both research and clinical settings to assess the severity of depression, will make a significant contribution. An example is the Patient Health Questionnaire-9, which can be recorded via the app and used to assess possible clinical improvements after app use or NFB intervention [14].

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