Research on Mental Health Service Design for the Elderly Based on Smart Home Environment

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Abstract
Because of rapid global aging, more than 14% of older people face psychological problems such as depression and anxiety, which directly affect their physical health and quality of life. To deal with these problems in time, we propose a design scheme of mental health services for the elderly based on smart home technology. The rapid development of smart home technology offers an unprecedented opportunity to improve the health of older adults. Our design is designed to meet the needs of the elderly for intelligent health care, through a comprehensive understanding of the psychological state of elderly patients, to provide timely diagnosis and treatment support and medical services. In the smart home environment, we use non-contact sensing technology to collect the mental state data of elderly users in real time while using machine learning methods to predict and evaluate. With the elderly users as the centre, we have established a dynamic monitoring mechanism for the mental health of the elderly. This system not only provides elderly users with real-time mental health monitoring and professional psychological guidance, depression prevention and management, remote consultation and safety monitoring and other all-round services, but also effectively reduces the cost of traditional psychological diagnosis and treatment services, and solves the problem of shortage and inequality of medical resources. By proposing this service design scheme, we hope to improve the mental health problems of the elderly, thereby optimizing the quality of life of the elderly, so that they can enjoy a healthier and happier old age.

Keywords: Smart Home, Elderly People, Mental Health, Service Design

Introduction

The global population is aging rapidly, and the number and percentage of elderly people are increasing significantly. Population aging is becoming a worldwide trend. Mental health problems like depression have increasingly become a focus of attention among elderly people. This issue not only greatly affects the individual's physical and mental health but also brings tremendous challenges and burdens to social pension systems, healthcare systems, and community healthcare systems. For example, with almost 20 years of development in China, urbanisation and population aging trends are becoming more apparent, and medical services have become one of the urban residents' most rapidly growing demands. The residents prefer large hospitals since China's family healthcare service institutions are still in their early stages. They seldom choose community healthcare hospitals/centres, which puts great pressure on general hospitals and has increased medical contradictions. The increasing number of senior citizens in China who live independently prefer staying at home rather than in hospitals or nursing homes, which means they either live alone or with a partner. As they age, their physical, auditory, visual, and cognitive abilities decline, and long-term care becomes crucial for them. However, due to various reasons, many older people prefer to age in place. Therefore, there is a need to develop technologies and services that enable older people to live at home and improve their quality of life. Nevertheless, the uneven distribution of medical resources, shortage of elderly service personnel, and high costs have resulted in home care services failing to fully meet the health, safety, and well-being needs of older persons. Moreover, there is a lack of mental life support services for the elderly, who often experience negative emotions such as loneliness and sometimes cognitive decline. Emotional problems can lead to mental problems, which in turn affect physical health, creating a vicious cycle that has a devastating impact on the physical and mental health of the elderly. Additionally, depression in the elderly is characterized by low detection rates and difficulty in sustaining treatment. As the population ages, these related problems will become more prominent.

Depression is a serious human mental disorder, because of its high incidence and high harm in the elderly population, depression has been widely concerned by the world. The disease is generally manifested as low mood, depression, slow thinking and cognitive impairment, impaired physical activity and other symptoms, and these symptoms usually last for a long time. With the rapid aging of society, the risk of depression in the elderly is increasing. Studies have shown that subjects with severe depression may even show suicidal tendencies and self-harming behaviors,[1] which puts a great burden on the patients and their families and the whole human society. Depression is also characterized by a high recurrence rate, and according to statistics, patients have a recurrence rate of more than 50% even after treatment and recovery. According to the World Health Organization, the number of people suffering from depression worldwide has reached 980 million. Depression has become a major typical disease with a wide range of patients, seriously affecting human physical and mental health and social development and progress. Therefore, the timely diagnosis and rehabilitation of depression has gradually become a hot topic of widespread concern in human society. In clinical practice, doctors first identify the symptoms of depression through face-to-face clinical consultation, to measure and evaluate the severity of depression. The doctor will understand the patient's medical history through communication and observation. Symptoms and daily living conditions, etc., and standardized questionnaires or scales were used to assess the severity and frequency of depressive symptoms.[1] During these visits, clinicians assess both verbal and non-verbal indicators of depression symptoms: including monotone pitch, reduced speech speed, reduced volume, fewer gestures, and less eye contact, and if these

symptoms continue for two weeks, the patient can be considered to be having a major depressive episode. This is a large number of people with the disease. According to data published by the World Health Organization in 2018, the prevalence of depression in older people over the age of 65 is conservatively estimated at 10%-15%, and even some estimates range as high as 45%. Although geriatric depression has become a serious public health problem, it is rarely concerned by public opinion, and this group of elderly depressed patients is also in a state of "aphasia". At present, the identification rate of geriatric depression is low, and the treatment is inadequate, and with the deepening of the aging population, the problem will become more prominent. With the continuous development of smart homes, various household appliances have become intelligent and Internet-based,[2] and artificial intelligent-related intelligent algorithms are emerging in an endless stream. Then, mental health services for the elderly are implanted in smart homes, non-contact sensors are adopted to collect daily elderly data, and artificial intelligence methods are used to conduct real-time data analysis. Determine whether the elderly is in the stage of depression; Then according to the results of the judgment analysis, the corresponding processing, while supporting the safe monitoring function, at any time to ensure the safety of the elderly, to achieve a full range of intelligent protection. Therefore, based on the smart home environment, this paper will design and study the mental health services for the elderly, and propose a smart home service design that pays attention to the mental health of the elderly.

Related Research

1. Service System Based on IoT and Digital Twins

Service System based on IoT and Digital Twin for remote smart home-device control with HMI-driven user interaction aims to improve home healthcare. The main objective is to build an integrated smart home system that merges the physical and virtual ranges via the IoT, VR, AR, and MR technologies to enhance the lifestyle of old users. Implementing smart home device control with digital twin technology, using multiple data sources, helps bridge the physical and the virtual world effectively and enables all-around monitoring and dynamic management of home devices at any time.

In addition, using VR, AR and MR technology can enhance the user experience of the interaction of smart devices, making remote control more engaging and accurate. The investigation results demonstrate that the system is quite pronounced for the teleoperation of smart home systems and interconnection of devices and can considerably improve these devices' operational reliability and safety.

Based on IoT and Digital Twin, this service system can access AI technologies such as algorithms, computing power, and big data, and it can use non-invasive monitoring methods to understand the health status of the elderly.

2. Non-invasive or Contactless Monitoring

Mental health monitoring is one of the most potent tools for treating psychological problems. The sensing methods that can be used are invasive (contact) or non-invasive (contactless), depending on how each method interacts with the subject.[3]

It is important to note that contactless methods represent a new emerging trend. Their application scope is expanding due to the advantages they offer. These advantages include the

fact that they can collect real-time data such as physical signs in the form of facial expressions, gestures, and activities, as well as physiological signs in the form of heart rate or respiration. Furthermore, a modern-day Smart home is a typical example of implementing a contactless sensing method for the early detection of a depressive episode with the timely provision of services and subsequent intervention.

Muhammad Nouman and his colleagues published a paper in 2022 introducing three ways of monitoring mental health, especially focusing on non-invasive methods to monitor mental health. The research is a detailed review of current technologies and approaches working with non-invasive monitoring based on mental health problems like depression, anxiety, and stress. Various studies are compared to demonstrate the effectiveness and reliability of different contactless sensing techniques. Contactless Sensing and Its Benefits (i.e., collecting physical and physiological signal data in real-time without interfering with the subject) make the body sensor data analysed by applying machine learning techniques for behavioural pattern inferences indicating a corresponding user's mental health states.[3]

Based on previous studies, it is important and necessary to use contactless monitoring technologies which are used for monitoring mental health with smart home service systems. These technologies are potentially useful and crucial in mental health monitoring because they directly link sensing methods to the identification and monitoring of mental health conditions. Non-contact sensing techniques for checking facial expressions, gestures and vital signs can detect the mental health conditions of individuals.

3. Artificial Intelligence Technology

Signs of depression are mainly divided into biological signs and behavioral signs. Although some biological signs have been considered to be closely related to depression, they are not specific signs of patients with depression. In addition, because the experimental conditions of different studies are difficult to achieve unity, the conclusions obtained are inconsistent or even contradictory. With the rapid development of the Internet and the continuous improvement of computing power, artificial intelligence has become increasingly mature in speech recognition, computer vision, natural language processing and other technologies, and has been applied more widely in the medical field. It can help doctors to make diagnosis more scientifically and efficiently by learning various forms of knowledge such as patient behavior and text.[2] Based on this, a large number of studies have proposed behavioral signs of depression, including visual signs and verbal signs.

Visual signs include body movements, gestures, subtle expressions, and periodic muscle movements. Girard et al. proposed a social withdrawal hypothesis to explain the non-verbal behaviors of depressed individuals,[4] arguing that depression is characterized by the reduction of communicative behaviors and the increase of non-communicative behaviors, in other words, the signals expressing accessibility should be reduced, while the signals expressing hostility should be increased. Through the facial action coding system, it is found that people with depression produce fewer affectionate expressions (e.g., raised lip corners), head movements and more non-affectionate facial expressions (e.g., contempt, tight lips).

Language signs include phonetic, grammatical, and semantic aspects. As a way of expression, language can express an individual's inner thoughts. By systematically analyzing a person's language, we can understand how depression affects his feelings and mental state. In terms of speech, people with depression tend to show a slowdown in their speech speed, they may

express their ideas more slowly and obtusely, or they may pause for a long time while speaking; The tone of voice may become monotonous and dull, lacking natural variation and emphasis: the volume of speech may also be relatively low,[5] the voice may become low or soft, and the voice may even be weak or unclear. Patients with depression will also over-focus on negative thoughts and emotions, lack interest and confidence in positive things and possibilities, and use more negative evaluation words when expressing. To sum up, it is necessary and promising to introduce artificial intelligence technology to screen behavioral signs of depression.

Based on the universal law of machine word learning, Wang extracted the features of the sample data set, and then choose the appropriate classifier model based on the guide. IveJ et al. proposed an RNN architecture that incorporates attention mechanisms to predict potential depression patients: due to the combination of attention mechanisms, this model can extract important text elements and make effective predictions.[6] Coppersmith et al. used LSTM network to quantify the text signal of suicide attempt in their study on whether there was suicide attempt in the text of social network, and captured the context information between the text contents through the model, so as to obtain the text content related to suicide. Chlasta et al proposed an ensemble learning method based on convolutional neural networks,[6] which achieved good performance on AVEC2016 dataset. Lu Xiaoyong et al. proposed a model combining residual idea and attention mechanism to solve the problem of structural complexity and low recognition rate of the deep neural network method. The accuracy of the model reached 76%. Li Jinming et al. studied feature design and network architecture, proposed a multi-scale audio difference normalization (MADN) feature extraction algorithm, and based on this algorithm, proposed a depression recognition regression model DRAudioNet.[6] The mental state of patients with depression is related to the changes of their facial expressions, and the common features of patients' facial vision are dullness, depression, desolation and stuttering eyes. In a study of psychomotor disorder related to bipolar disorder, people with depression had longer reaction times on swords-looking tasks. In addition, depression identification, deep learning technology and diagnosis methods of facial visual features for the elderly are generally divided into two categories. One is the visual local method, which is based on previous studies on facial features of patients with depression and seeks one or more types of local features related to depression as the data input of the deep learning model. The number of features required by this method is small. In the training of the model, it is easier to converge. Another method is the visual whole method. In order to avoid the information loss in the process of feature extraction, the whole face information is used as the input of the model to achieve automatic feature extraction. However, this method requires training through large amounts of video data, as well as building complex deep learning models.

The Elderly Mental Health Problem Identification Algorithm Design

1. Diagnosis Methods Based on Text Features

With the development of science and technology and online social platforms, people use online social networks (OSNs) more frequently to express opinions and emotions. It provides researchers with a novel and effective way to detect individual patterns of emotion, communication, activity, and social behavior. Existing research has shown that various types of information on online social networks (OSNs) can help predict the early stages of depression.[7] However, studies using machine learning methods to complete depression detection tasks still do not have high classification performance, suggesting that there is a lot

of potential for improvement in its feature engineering. Therefore, combining the automatic feature extraction function of deep learning technology and the characteristics of Chinese text, this paper proposes a classification method of Chinese depression.

1) Construction of Emotional Dictionary of Depression

In natural language processing tasks such as text classification and sentiment analysis, sentiment dictionaries usually play a major role and can influence the performance of the task. However, in the research of emotion dictionaries in the field of depression, the construction of emotion dictionaries is still in the preliminary stage, and there are few related emotion dictionaries. Therefore, by using web crawler technology to obtain the relevant depression text data, and combining the characteristics of the basic emotion dictionary and the data of depression patients, the English depression emotion dictionary is constructed and expanded. The specific steps are shown in Figure 1:

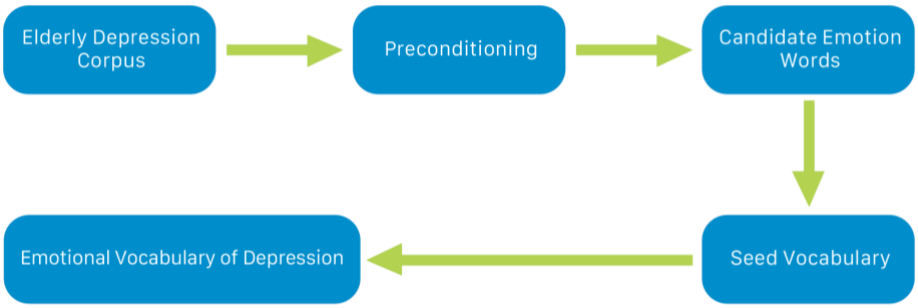

Figure 1. Construction of emotional vocabulary in the elderly with depression.

2) BERT-Based Word Recognition Model for Depression in Elderly People

BERT-W model is based on the depression domain emotion dictionary recognition model, which has stronger domain generalization ability and understanding ability, so it has more prominent advantages in depression tendency recognition task of online social texts. The elderly mental health service design designed in this paper will use this model to identify depressed words of the elderly,[8] as a basis for the mental health of the elderly. The workflow structure of this model for classifying depression in the elderly is shown in Figure 2.

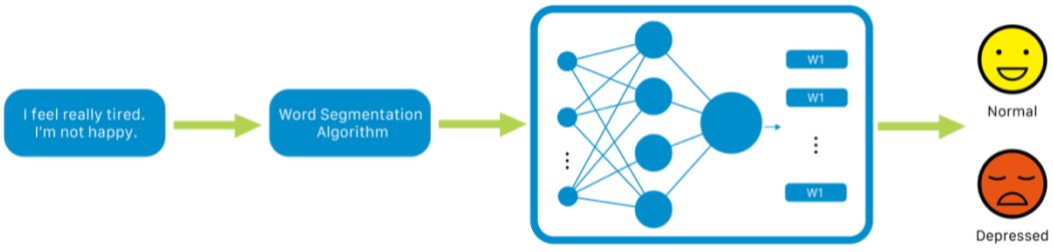

Figure 2. Workflow of depression classification in the elderly people.

2. Diagnostic Methods Based on Acoustic Features

1) Speech Feature Extraction

For the recognition of depression in the elderly, voice is an important feature. Based on the smart home system, the speech of the elderly can be obtained at any time, and the mental health problems of the elderly can be predicted in advance through the recognition and judgment of the speech by the machine learning algorithm. The extraction of speech features refers to the process of removing redundant information from the original data and extracting features with obvious distinguishing ability, which can realize the compression of feature dimensions and improve the computational efficiency and generalization ability of the model. Before the multi-modal feature fusion, the features of each mode should be extracted accurately and richly to make full use of the information contained in each mode.[8] The process of feature extraction is shown in Figure 3.

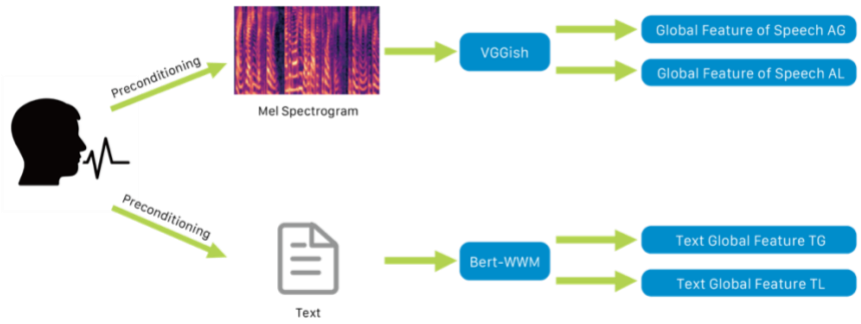

Figure 3. Speech global feature extraction.

2) Speech Recognition Model

The attention global awareness gating architecture consists of a feature extraction module and a Multi-mlp module. In the feature extraction module, we use the VGG16 model to extract high-dimensional depth spectral features. Multi-mlp is the backbone network module of the model used in this paper,[9] which is composed of multiple parallel MLPS. Figure 4 below shows the overall framework of the system.

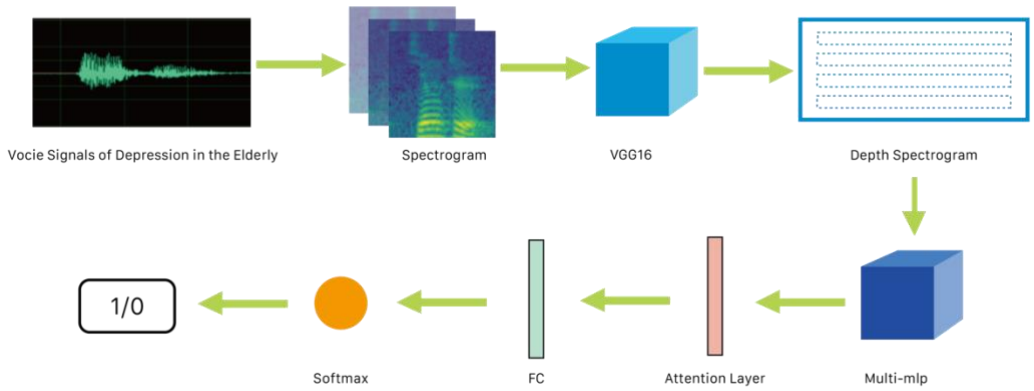

Figure 4. Speech recognition model of depression in the elderly people.

First, we convert the original speech signal after noise reduction into a spectral graph, which contains two dimensions of information, the horizontal axis represents the time information, and the vertical axis represents the frequency information. The spectrogram is then input into the pre-trained VGG-16 model to extract the 4096-dimensional depth spectral features of its penultimate layer: After that, the extracted features are input into the Multi-mlp module for mutual communication between features, and then connected to the attention layer to obtain the global key information. Finally, the output features are sent into the fully connected network and activated by SoftMax for depression classification recognition.

3. Diagnostic Methods Based on Facial Visual Features

1) Data Collection

In recent years, facial video-based depression recognition tasks have attracted much attention in the fields of computer vision and deep learning. Depression is a common psychological disorder, and research on efficient automatic depression recognition methods can help doctors better diagnose and treat patients. The overall process of depression recognition task based on face video is shown in Figure 5, which includes depression data acquisition, facial data preprocessing, data set analysis, model building, depression feature extraction, regression analysis and result prediction, etc. In the depression data acquisition segment, a large amount of facial data is usually collected on both depressed and non-depressed patients. This is the first step in completing the task of identifying depression. Then, in the process of facial data preprocessing, the data collected in the first step is usually cleaned and normalized for subsequent learning and recognition.[10] The third step is data set analysis, which usually analyzes the collected data, its validity, and the characteristics of the data set. The fourth step is model building and depression feature extraction, which usually uses machine learning algorithms or deep learning algorithms to build models and extract facial features from facial data according to the characteristics of the data. Finally, the extracted facial features are analyzed and processed to realize depression recognition.

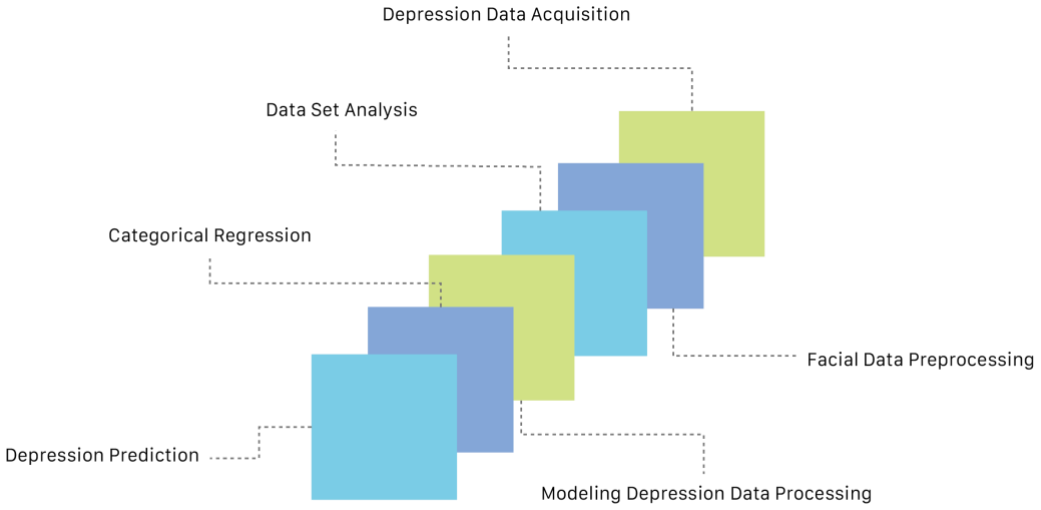

Figure 5. Task flow of depression recognition based on facial video.

2) Model

Depression is a long-term mental illness, and the emotions expressed by the subjects during the interview are gradually accumulated. Therefore, depression cannot be accurately identified only through short-term fragment features, and it is necessary to integrate the learned short-term features to further capture the long-term dependence relationship. In this paper, the LSTM model is used to fuse the short-term facial depressive features extracted by IC-STDM to capture the remote structure of motion features.

The fusion process is shown in Figure 6, where multiple short-term features are entered into the LSTM as input sequences. The principle of LSTM is to add three gate controllers based on recurrent neural networks, namely input gate, forgetting gate and output gate. These gate controllers can help the network better process sequence information while also avoiding problems with disappearing or exploding gradients.

In LSTM, each time step represents a short-term feature. The trained LSTM model is used to make predictions about the new data. Then, the hidden layer of LSTM is used for feature fusion and information transfer, and long-term motion features in short-term feature sequences are learned. The relationship between facial expressions and depression degree is analyzed. The prediction result of depression degree is calculated by the fully connected layer.

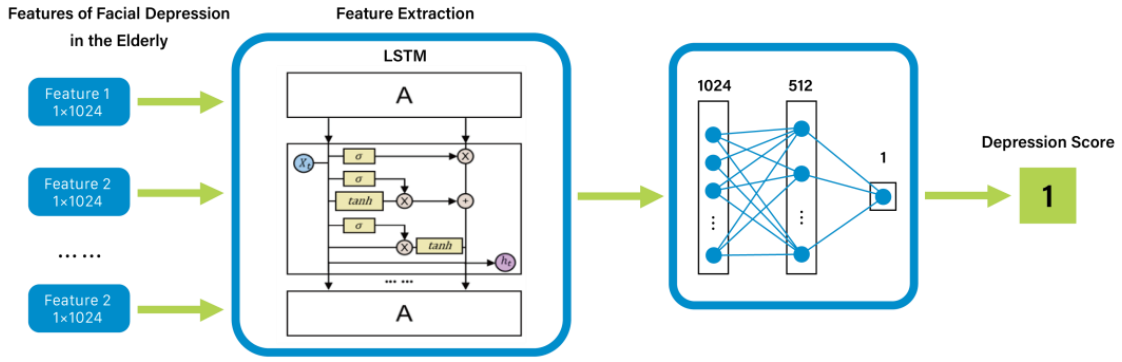

Figure 6. Feature fusion prediction architecture based on LSTM.

Design of Elderly Mental Health Service Scheme Based on Smart Home

In the context of a smart home environment, this paper applies the current advanced machine learning algorithm to analyze and process the text, voice and facial expressions related to depression of the elderly, which can predict the psychological well-being of the elderly in advance. Based on smart home, the text information typed online by the elderly is captured for word segmentation processing and training, and artificial intelligence is used to predict whether there is a tendency of depression through the online chat information typed by the elderly. In addition, the smart home collects the voice information of the elderly at home, adopts the voice conversion method,[11] and runs the artificial intelligence model to predict the mental health state of the elderly. Finally, the expression information of the elderly at home is collected, and the mental health of the elderly is judged through the inference of the neural network. Finally, the mental health service plan for the elderly in this paper includes the above three non-contact prediction methods, the combination of which can help prevent the mental health problems of the elderly in a more comprehensive way. The prediction

results will be timely notified to their families through phone calls and short messages, and at the same time, a big data system will be established in the design of the plan. Big data analysis is used to predict the mental health tendency of the elderly, and at the same time, some music to relieve stress and ease mood will be recommended according to the mental health of the elderly, which can guide the elderly out of the risk of depression to the greatest extent. The design process of mental health services for the elderly in this paper is shown in Figure 7.

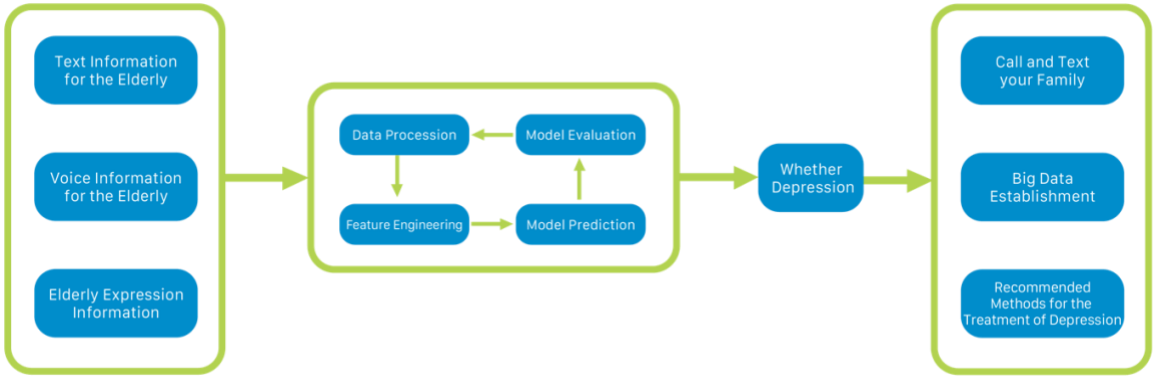

Figure 7. Design process of mental health service for the elderly.

Conclusion

With the intensification of global aging, the mental health of the elderly is a very important issue. Based on the smart home platform, this paper designs a scheme that can help predict the mental health problems of the elderly in advance. The scheme applies the current advanced machine learning algorithm to the platform. The text information, voice information and facial expression information of the elderly in their daily life are collected by non-contact sensors, and the mental health status of the elderly is identified and predicted in advance through the pre-processing of algorithms and the prediction of machine learning models. In combination with the predicted results, the program will notify the elderly's family members of these information and screen treatment methods. Help the elderly out of the risk of depression. The mental health service design for the elderly based on the smart home environment proposed in this paper is expected to help the elderly spend their old age peacefully.

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