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Predicting the Severity of Major Depression Disorder with the Markov Chain Model

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***Abstract*—Depression is estimated as the largest cause of disability in the world, and the fourth largest burden of disease, by the World Health Organization. Delayed detection escalates the risk of the patients experiencing serious mental health problems. The long-term analysis of depression symptoms required for accurate diagnosis is not possible in many cases. The Markov Chain Model provides a method to evaluate sequences of information in various situations. In this article, the most common form of depression, known as Major Depressive Disorder (MDD), is analyzed and modeled by the Markov Chain Model. The future emotional state of an individual can be predicted by solving the equations derived from the model according to available current information about that individual's current mental status. Finally, the method is analyzed under a clinical scenario that indicates the accuracy of the applied method and the results of the prediction. The proposed method in this paper can be used to diagnose anxiety and schizophrenia as well. It is expected that the proposed approach can stimulate fruitful discussion and research essential to improve the theoretical methods and interventions in mental health studies.**

Keywords-Mental health; major depression disorder; Markov chain model; Psychotherapy

I. INTRODUCTION

Preventing mental disorders is one of the major mental health issues. Depression is the most common mental disorders, yet is often poorly detected within both community and hospital settings', resulting in poor quality of life for those affected, including the family members. Depression is estimated as the largest cause of disability in the world, and the fourth largest burden of disease by the World Health Organization (WHO). Effective detection and management of depression have been identified as priority areas within the national service framework for preventative mental health and reduction of suicidal behavior. It is noteworthy that in approximately 75% of completed suicides the individuals had seen a physician within the year prior to their death, 45%-66% within the month prior. Approximately 33% - 41% of those who completed suicide had contact with mental health services in the year prior to their death, 20% within the month prior.

The challenges for psychiatrists and health care specialists include detecting depression in a timely manner and measuring the severity of depression, especially during therapy sessions. Delayed detection escalates the risk of the patients experiencing serious mental health problems. Early detection and even potentially predicting depressed states can lead to effective prevention and management [1]-[3].

Due to the nature of mental disorders, short-term and intermittent observation of the symptoms most often cannot yield an accurate recognition. Depression generally presents as a long-term cumulative negative emotional condition. Thus, long-term analysis of depression symptoms is required to detect it correctly.

The Markov Chain Model provides a possibility to evaluate sequences of information in various situations [4]. In this study, the most common form of depression, known variously as Major Depressive Disorder (MDD), major depression, unipolar depression, or clinical depression, is analyzed. In MDD or unipolar depression, there are no periods of mania because the mood remains at one emotional state or "pole". A Markov chain model of unipolar depression is presented to predict emotional states of an individual in the future according to available previous and current information about that individual's emotional status. The model is analyzed under a clinical scenario [5].

In the following sections, MDD, the relevant modeling context, and some techniques useful in gathering data from individuals' emotional states are described in section II. MDD is formally analyzed and modeled in section III. Finally, an actual clinical scenario is evaluated with the Markov chain model and the results of the evaluation are demonstrated in diagrams in section IV.

II. MAJOR DEPRESSIVE DISORDER

Depression is the most common disorder in mental health, and Major Depressive Disorder (MDD) is recognized as the most frequent form of depression. The symptoms of MDD vary in type and severity. Mostly, life events and responses to cumulative stress have an acute onset and last for days or weeks; prolonged distress may trigger MDD. The severity (conceivable as depth) of MDD is typically divided into three classes, *mild*, *moderate* and *severe.* Consequently, four boundaries on the level of symptoms can be considered to evaluate the severity of depression, as shown in Table 1.

Currently, verbal reports, such as clinical consultations or questionnaire responses by patients, their family, or caregivers, are the common methods of assessing depression [6, 7]. Nevertheless, advances in pervasive and ubiquitous technologies and intelligent systems have led to the development of innovative methods for gathering relevant psychological information from individuals. For instance, some ambient intelligent agent models have been developed for use in monitoring patients' states and behaviors with environmental sensors over time [8-10]. In such systems, facial actions, vocal prosody, changes in weight or sleeping patterns in individuals undergoing observation are measured automatically by implementing a simple sensing mechanism that can be naturally integrated into the living environment (e.g., clinic, home) for capturing symptoms of depression [11]. A great amount of information about an individual's cognitive and emotive status can be acquired from eye movements [12], and a human-robot interface which uses a video-based eye-tracker can be applied to recognize cognitive and emotional status.

Considering individual's daily mood information for approximately a one-month interval is sufficient to predict the severity of depression in the following weeks. Actually, measuring the severity of depression is a significant issue in cognitive behavioral therapies. Some standard metrics such as the Beck depression inventory can be considered to evaluate the collected data in terms of the depressed mood rate [13]. Due to the cumulative nature of depression, the major problem is that a long-term examination of the symptoms is required to make an accurate decision about an individual's depression status; as a result, it is not

TABLE I. BOUNDARIES FOR THE SEVERITY OF DEPRESSION.

State	Bounds
None	0-25%
Mild Dep.	25-50%
Moderate Dep.	50-75%
Severe Dep.	75-100%

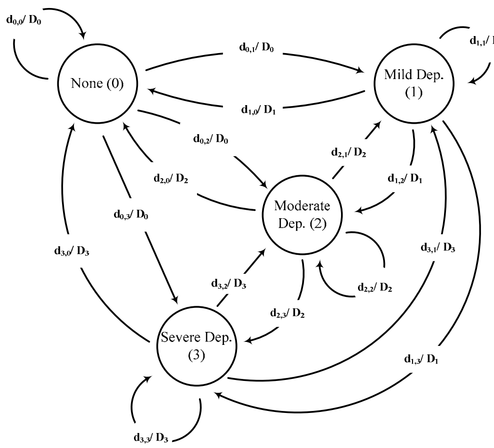


Figure 1. The Markov chain state diagram for analyzing the severity of depression.

uncommon that observation ceases before a full diagnosis can be made. Since the mathematical method of the Markov chain model can specify the probable future state of an animate system in congruence with the sequence of its previous states. In this case, here, the mathematical method of the Markov chain model as an efficient solution that can be applied in an ambient intelligent system to predict the severity of depression, using selected physiological and emotional information about an individual.

III. A MARKOV CHAIN MODEL FOR SEVERITY OF MDD

As mentioned in the previous section, depressed mood rate of an individual can be estimated according to recorded physiological and emotional information and then measured against standard rating scales [14]. Now, a mathematical method is proposed to analyze the depressed mood rates to predict the severity of MDD. The method is described in following five steps:

- Monitoring and recording data about an individual's depressed mood rates for at least one month.
- Making the Markov chain model of the severity of MDD according to the collected data.
- Deriving differential equations from the Markov chain model by means of a transient matrix.
- Solving the set of Markov chain differential equations.
- Predicting the severity of MDD in the individual according to the state described by the maximum valued answer.

Now, the steps summarized above are explained in detail. The Markov chain model is used as a formal method to evaluate the depressed mood rates. The dominant Markov chain model has four states in correspondence with three classes of the severity of MDD, as shown in Fig.1. Two counter variables, $d_{i,j}$ and D_i are defined to form the model. Variable $d_{i,j}$ counts the number of transitions from state i to state j , and variable D_i is defined in "(1)".

$$D_i = d_{i,0} + d_{i,1} + d_{i,2} + d_{i,3}\ . \tag{1}$$

Thus, the division ($d_{i,j}/D_i$) indicates the probability of transition from state i to j. Actually, the distributions of data between two states of the model is followed by *exponential distribution*. Solving the equations derived form the Markov chain model generates the probability of being in each state in a specific day. The calculation of $\pi_i(t)$ indicates the probability of being in state i in time t (1,2,3,…); t counts the number of days from the beginning of the task.

In this case, recording depressed mood rates for a one-month time interval including up to 30 days prior to the date of recording is sufficient. The probabilities assigned to the edges of the graph (Fig.1) are changed by weekly updates of the depressed mood rates diagram [15]. The psychological state of the individual under study can be evaluated by solving the probabilistic equations derived from the Markov chain model. According to the matrix form of Markov chain equations ($\pi' = P\pi$, P is the transient matrix), a diffrential equations set can be obtained as follows “(2)”:

$$\begin{cases} \pi'_0(t) = \delta_0\pi_0(t) + (d_{1,0}/D_1)\pi_1(t) + (d_{2,0}/D_2)\pi_2(t) + (d_{3,0}/D_3)\pi_3(t) \\ \pi'_1(t) = (d_{0,1}/D_0)\pi_0(t) + \delta_1\pi_1(t) + (d_{2,1}/D_2)\pi_2(t) + (d_{3,1}/D_3)\pi_3(t) \\ \pi'_2(t) = (d_{0,2}/D_0)\pi_0(t) + (d_{1,2}/D_1)\pi_1(t) + \delta_2\pi_2(t) + (d_{3,2}/D_3)\pi_3(t) \\ \pi'_3(t) = (d_{0,3}/D_0)\pi_0(t) + (d_{1,3}/D_1)\pi_1(t) + (d_{2,3}/D_2)\pi_2(t) + \delta_3\pi_3(t) \end{cases} \tag{2}$$

In the equations set, δ_0, δ_1, δ_2 and δ_3 are indicated in accordance with δ_k= — *(sum of the remaining multiplicands in the equation),* for example $\delta_0 = — d_{1,0}/D_1 — d_{2,0}/D_2 — d_{3,0}/D_3$.

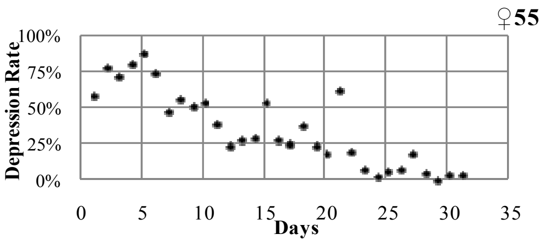


Figure 2. Depressed mood diagram of an actual case.

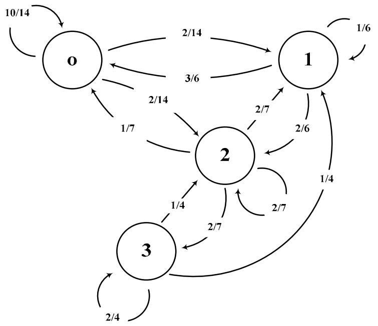


Figure 3. Markov chain state diagram for the case study.

The answers of the equations set “(2)” are $\pi_0(t)$, $\pi_1(t)$, $\pi_2(t)$, and $\pi_3(t)$, which specify the probabilities of being in each state in which $\pi_0(t) + \pi_1(t) + \pi_2(t) + \pi_3(t) = 1$. The differential equations can be solved by applying the *operators method*. After complex processes, the parameters (τ_0, τ_1 and τ_2) are obtained as the answers of the *Eigen equation* for the differential equations set. According to these three parameters, the form of the particular answer of the set is nominated. The whole answer (π_i) is calculated from the relation ($\pi_i = \pi_{ih} + \pi_{ip}$), in which π_{ip} is the public answer.

Furthermore, the constants (c_i) of the answers can be calculated by solving a set of equations that is formed using some initial values of the depressed mood rates with the same number of the constants. Finally, after a warm-up interval of approximately two weeks, the severity of depression of the individual under observation can be predicted according to the state i after t days, where:

$$\pi_i(t) = Max\ \{\pi_0(t),\ \pi_1(t),\ \pi_2(t),\ \pi_3(t)\}. \tag{3}$$

The maximum valued state indicates the mood condition of the individual “(3)”. Also, a more accurate definition of depression can be proposed here, that is, after a minimum of 2-4 weeks ($t > 14$), if $\pi_0(t)$ lacks the maximum value among the other probabilities, MDD is diagnosed.

IV. Scenario Of Use On An Actual Case Study

In this section, a psychological sample is analyzed and the severity of depression is predicted according to the method proposed in the previous section [16]. The relevant data were captured in one month by caregivers and the diagram of these data is seen in Fig. 2. In fact, this diagram is a clinical study of depressive illness of a married woman, aged 55, who developed a severe depression with few precipitating factors, culminating in a suicidal attempt with both drugs and coal-gas. She responded well to electroconvulsive therapy and amitriptyline. The treatment of the illness was entirely satisfactory, proceeding to full recovery within a month [17]. The mental state diagram for this case is formed in Fig. 3 and the transition matrix of the mental state diagram is seen below “(4)”:

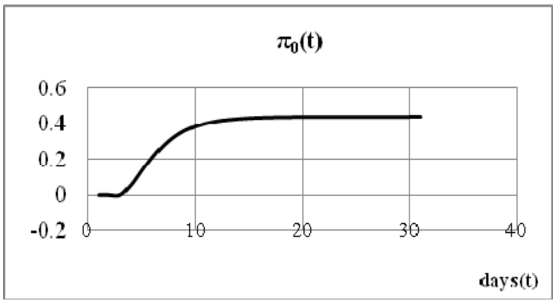
$$P = \begin{pmatrix} —4/14 & 2/14 & 2/14 & 0 \\ 3/6 & —5/6 & 2/6 & 0 \\ 1/7 & 2/7 & —5/7 & 2/7 \\ 0 & 1/4 & 1/4 & —1/2 \end{pmatrix} \tag{4}$$

For solving the differential equations of the Markov chain model, shown in Fig. 3, some mathematical engineering methods τ_0, τ_1 and τ_2 are calculated and relevant entities are obtained (τ_{i1} = —0.999971, τ_{i2} = —0.942825, τ_{i3} = —0.390536, for i = 0, 1, 2, 3). Additionally, the public answers (π_{ip}) are computed (π_{0p} = 0.436489, π_{1p} = 0.193997, π_{2p} = 0.193997, π_{3p} = 0.129330) to reach the final answers as follows “(5)”:

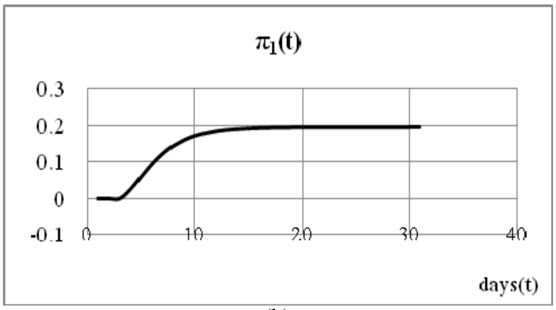
$$\begin{cases} \pi_0(t) = —35.062243e^{—0.999971t} + 36.871106e^{—0.942825t} — 2.807317e^{—0.390536t} + 0.436489 \\ \pi_1(t) = —15.583371e^{—0.999971t} + 16.387318e^{—0.942825t} — 1.247709e^{—0.390536t} + 0.193997 \\ \pi_2(t) = 498.677706e^{—0.999971t} — 499.851469e^{—0.942825t} + 17.811012e^{—0.390536t} + 0.193997 \\ \pi_3(t) = —124.632007e^{—1.072292t} + 124.215411e^{—0.863291t} —14.68200e^{—0.397750t} + 0.129330 \end{cases} \tag{5}$$

These answers indicate that the probability π_i in each day of the month shows slight difference with π_{ip}. Therefore, in this case, the probability of being in state (0) has the maximum rate (i.e. 0.4364) among the other states, which denotes that the individual should be in a healthy condition at the end of the month. The result is in agreement with the description of the case study, in which the treatment was entirely satisfactory and proceeded to full recovery within a month. Consequently, the proposed mathematical model can analyze and predict the severity of depression effectively and accurately. The probabilities of being in each state after 31 days are shown in Fig. 4, and finally they all are compared in Fig. 5. In practical applications, these diagrams should be modified every week and the most recent week's diagrams indicate the current mental state of the individual under observation.

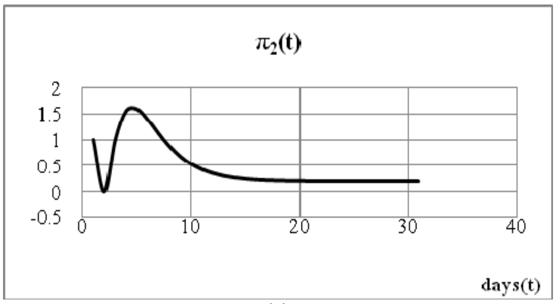
As seen in these diagrams a suitable warm-up interval must be provided for the sampling. According to the diagrams and the beginning fluctuations, a warm- up interval of approximately two weeks (0-14 days) seems suitable.



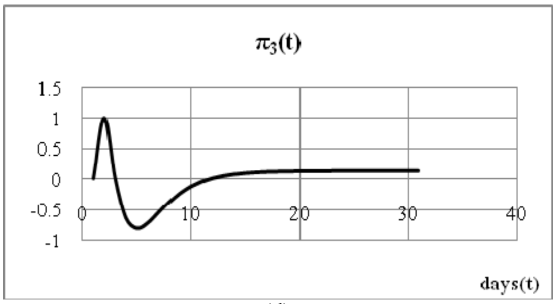
(a)



(b)



(c)



(d)

Figure 4. The probability of being in none state (a), mild state (b), moderate state (c), and severe state (d).

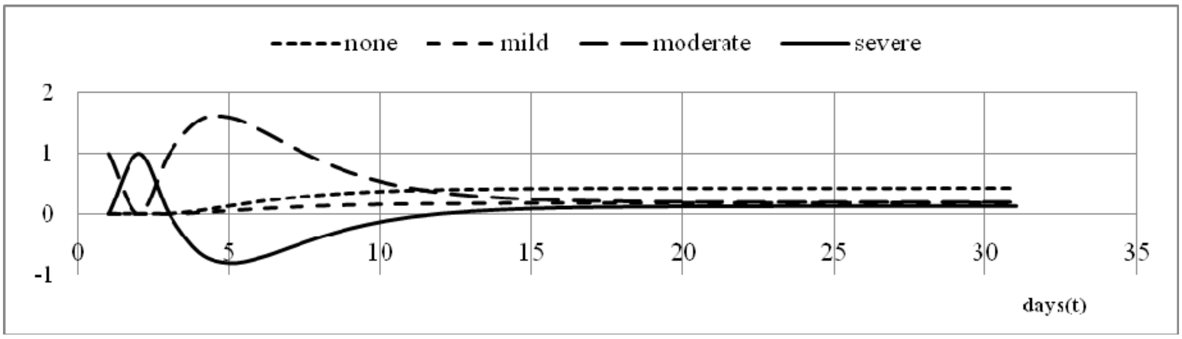


Figure 5. The comparison of the four state probabilities regarding the severity of depression.

V. CONCLUSION

Depression is the most common disorder in mental health and Major Depressive Disorder is recognized as the most frequent form of depression. One of the challenges for psychiatrists is to detect depression in a timely manner and to measure the severity of the depression accurately. Since it is common for depressed individuals to stop their therapy sessions before they can be properly diagnosed using traditional methods, the relative expedience of the proposed method is especially attractive.

This investigation suggests that ambient technologies and mathematical methods can be applied to the diagnosis and analysis of mental health problems in clinical research studies. In the present paper, the Markov chain model is used to use physiological and emotional data for predicting the severity of MDD. The proposed approach is fully described as a step-by-step formal method and subsequently the results of its application to a real clinical case confirm the accuracy of the method.

The objective is to establish a mathematical and computational approach to detect and evaluate depression for preventing this damaging illness. Furthermore, the method proposed in this paper may be useful in analyzing anxiety and schizophrenia as well, pending further research. Finally, we expect that the proposed approach can stimulate discussion and research essential to improving theoretical methods and interventions in mental health.

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