31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

A Framework for Wireless Monitoring of Mental Health Conditions

Upkar Varshney, *Member, IEEE*

Abstract— **Mental health management is fast becoming a major challenge worldwide as the incidence of mental illness has been increasing. It is affecting the quality of life as well as job productivity for a large number of people. Just like physical illnesses, people with mental illnesses can be monitored for a range of conditions and provided medical care as and when necessary. In this paper, we present an IT-enabled framework to support mental health monitoring. This includes comprehensive monitoring of patients for symptoms, behavior, and medication compliance. We utilize context-awareness as a way to develop a system for mental health monitoring. Several examples of future mental health monitoring are also presented.**

I. Introduction

Mental health is a state of successful performance of mental function, resulting in productive activities, fulfilling relationships with other people, and the ability to adapt to change and to cope with adversity [1]. Mental illnesses include all of the known and diagnosable disorders. While some mental illnesses cause relatively mild distress, others result in severe impairment and may require hospitalization [2]. According to WHO report on Global Burden of Disease [5], the uni-polar depressive disorders are the leading cause of burden of disease in developed countries, and it will become true for the entire world by 2030. Some major classes of mental illnesses and their examples are shown in Table I.

TABLE I
SEVERAL MENTAL ILLNESSES, SYMPTOMS AND TARGET POPULATION

Group of Illnesses	Example	Symptoms	Target population
Mood Disorders	Major depression	Lack of energy, sleep, and interests Suicidal ideations	Young adults, adults, and seniors
	Bi-polar disorder	Manic phase followed by depressive phase	Young adults, adults, and seniors
Cognitive Disorders	Alzheimer	Severe forgetfulness	Older adults and seniors
Personality disorders	Obsessive-Compulsive	Distress in job and family situations	Young adults and adults
Schizophrenia	Paranoid Schizophrenia	Hallucinations Delusions	Young adults, adults, and seniors
Anxiety Disorders	Panic Disorder	Panic attacks Excessive worrying	Young adults, adults, and seniors
	Post Traumatic Stress Disorder	Excessive alertness Lack of sleep	All age groups
Eating Disorder	Anorexia Nervosa	Loss of weight Abnormal heart rhythm	Primarily young and adult women
Developmental Disorder	Attention Deficit Disorder	Inability to focus	Primarily children

There has been some work in applying monitoring technologies in managing mental health challenges and can be classified among the following categories: (a) design and development of systems to provide care for patients suffering from dementia, (b) monitoring of location and activities of patients, (c) detection of dementia and stress levels using computer games, activity monitoring, and EEG. Several examples include smart home or smart house, where different technologies are embedded to help patients in their daily activities [10], stray prevention for patients with dementia using RFID, GPS, GSM, and Geographic Information System (GIS) [9], and, design of systems to provide prompts to a user with dementia for guidance through the activity of hand-washing [11]. The detection of dementia has been addressed by using changes in EEG signal [12] and sudden fluctuations of activity [4]. Additionally, stress monitoring is performed using clothing-embedded transducers for ECG [8]. The system utilizes heart-rate-variability (HRV) to quantify stress level.

Considering that mental health challenges could seriously threaten the global health and productivity, more work is needed in monitoring a range of mental health conditions for patients in diverse environments such as homes, assisted livings, nursing homes, and remote places (Figure 1). In this paper, we present a framework, called Mental Health Monitoring Framework (MHMF), designed to address how different conditions can be monitored by using a generalized monitoring system and how context-awareness can be used to assist such monitoring. Several examples of mental health monitoring are also analyzed and two metrics for evaluation, including the probability of correct diagnosis and the mental health cost savings are presented and utilized. The framework and its major components are shown in Figure 2.

Manuscript received April, 7 2009. This work was supported in part by RCB Research Program at Georgia State University.

Upkar Varshney is with the CIS Department, Georgia State University, Atlanta, GA 30302-4015 (phone: 404-413-7382; e-mail: uvarshney@gsu.edu).

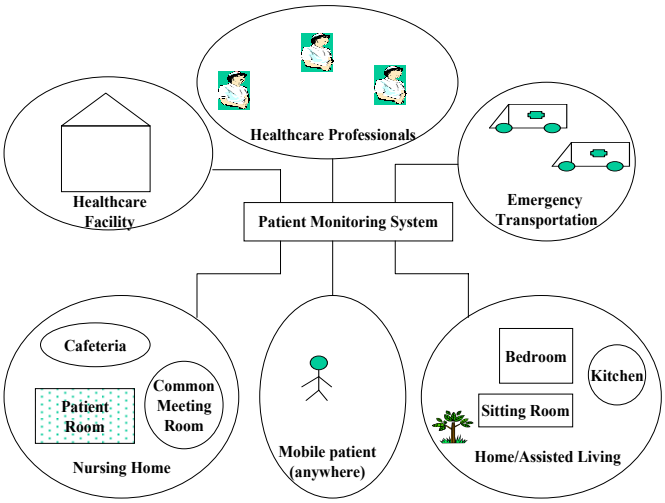

Fig. 1. The diversity of mental health monitoring environment

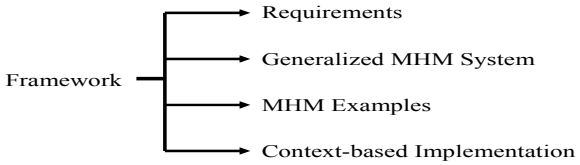

Fig. 2. Mental health monitoring framework (MHMF) and its components

II. Requirements of Mental Health Monitoring

Mental health monitoring includes monitoring for related physical conditions such as sleep patterns, weight loss as part of depression and suicidal behavior, and weight gain due to inactivity and certain medications. There are many challenges in mental health monitoring including monitoring of behavior, which is much more complex and dynamic than physical symptoms, and requires new methods and techniques to measure several parameters and evaluate behavioral conditions including suicidal and homicidal ideations. This requires matching or mapping of multiple parameters and vital signs to an estimate of a condition.

The need to protect privacy is enormous and mental health monitoring should protect patient privacy and information collected in the monitoring process just like any HIPAA compliant monitoring. The patients and family members would have to be convinced and must be able to see the benefits of monitoring and any improvements to the overall mental health of the monitored patients. The patient co-operation is critical to the success of monitoring even if the sensors and hardware are working perfectly all the time.

There is also a higher chance of addiction to prescription drugs, controlled substances, and even illegal drugs. The monitoring for medication compliance could be facilitated by designing and employing smart-pill-containers, which dispense medications and also generate alerts for physicians for compliance and/or abuse.

Patients with mental health problems are likely to have cognitive decline or problems. Therefore, monitoring systems and patients' surroundings should offer them support in helping their day to day life. Additional challenges include possible paranoia with technology, diversity of patients such as child and adolescents, adult, and geriatric patients.

The symptoms and signs that require immediate physician attention or hospitalization are suicidal ideation, homicidal ideation, unstable or out of control due to mania, agitation, acute psychosis, dementia with severe behavioral problems, dementia with psychotic symptoms, serious withdrawal for drugs, and rapid, sudden and severe deterioration of functioning. The patients living in assisted living and nursing homes may require attention and/or hospitalization, if one or more of the followings occur: demanding and loud patient causing disruption, patient threatening to leave against medical advice, or showing repetitive disruptive behaviors and becoming dangerous to other residents.

III. A Generalized System for MHM

A system for MHM will allow monitoring of patient's mental health from a distance such as homes or assisted living facilities in remote or rural areas. The goal is to obtain sufficient information for a making a diagnosis of the mental health condition. This can be done by comprehensive evaluation using history of present illness, past psychiatric and medical history, substance abuse history, family and personal-social history, review of major health systems, and mental status examination (MSE).

Next, we present the generalized system for mental health monitoring (GSMHM), designed for monitoring various mental illnesses. GSMHM can be populated by the identified symptoms [2] which can be monitored for several major illnesses shown in Table II. Then the symptoms are broken into behavioral and physical symptoms. These symptoms can be received from multiple sources such as patients, family members and/or sensors. These are then processed based on specified patient-specific thresholds and then reported to the designated healthcare professional.

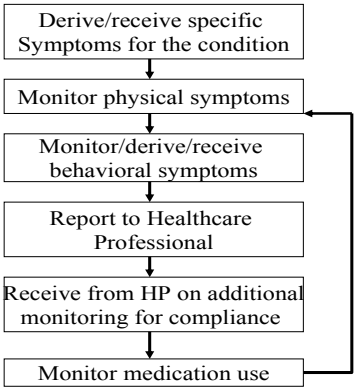

Fig. 3. The process model used in the generalized system for mental health monitoring (GSMHM)

TABLE II
MONITORING OF SPECIFIC MENTAL ILLNESSES

Specific Illness	Specific Monitoring
Post Traumatic Stress Disorder (PTSD)	Activity monitoring, sleep monitoring ECG for palpitations
Obsessive-Compulsive Disorder (OCD)	User activities and evaluating if these activities are repetitive
Panic Disorder (PD)	Chest pain, shortness of breath, heart palpitations, sweating and agitation
Eating Disorder (ED)	Weight loss, amount/frequency of swallowing of food, depression, anxiety and substance abuse, and, abnormal heart rhythm
Major depression	Weight loss, food, sleep , behavior monitoring (activity, mood, socialization)

The healthcare professional will inform the system on what else needs to be monitored, for example, the monitoring of depression will involve monitoring of sleep pattern, weight loss, food consumed and behavior. The network architecture for GSMHM using wireless networks is shown in Figure 4. The monitoring includes vital signs and activity levels, supplemented with subjective symptoms from the patient and objective symptoms from family members. The symptoms reported over a wireless device include sleep, appetite, energy level, apprehension, lack of interest, psychosis, and, suicidal and/or homicidal behaviors (Figure 4). The patient's picture (or a short video-clip) is transmitted to a healthcare professional to check one of several conditions including anxiety symptoms, pain-score, and level of depression. The periodic transmission of such information is compared with previous information for detecting any changes in the patient's conditions. Any discrepancy in the information by a patient and/or family members and the information obtained by monitoring are used to check the authenticity of symptoms, if faked to obtain secondary gains. The current system relies on family and patient, however, we are working on scenarios where the family is not available or reliable. More work is also needed in addressing potential incorrect diagnosis due to errors/bias in one or more measured or specified parameters.

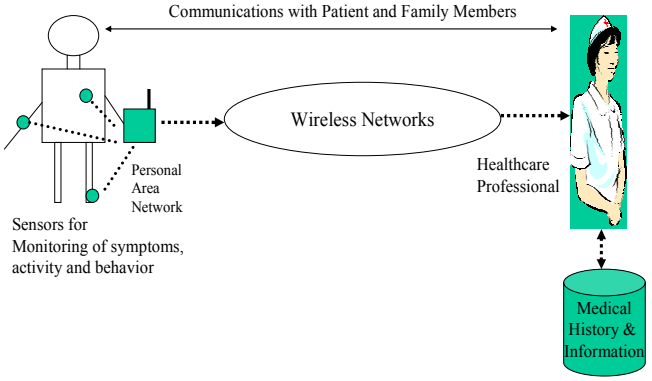

Fig 4. A network architecture for GSMHM

IV. A CONTEXT-BASED ALGORITHM

For mental health monitoring, the context is generated using weighted sum of different input variables to generate probabilities, which are then mapped into likely contexts (Figure 5). It utilizes weights and available information, and accounts for missing or unreliable information. This can lead to effective MHM due to personalized weights, thresholds, and possibility of learning from previous outcomes to improve future accuracy, and help a healthcare professional in medical decision making. The steps could include

- Assign weights to different vital signs and parameters (based on patient history and medical knowledge)
- Use known connections between parameters & conditions
- Assign some weight to cover the uncertainty
- Put choices in rank-order for healthcare professionals

A simplified version of algorithm for dementia and depression using multiple parameters is shown in Figure 5. The algorithm can include daily activities, lack of interest, medication compliance, psychosis, and suicidal/homicidal ideations. Some weights are added for unknown/unreliable conditions to meet the goal of zero false negatives at the expense of slightly higher false positives.

{History} If patient-history = depression
Add Points-history to Points-depression
Else If patient-history = dementia
Add Points-history to Points-dementia
If patient-history = unknown {Add some weight}
Add Points-history-unknown to Points-depression
Add Points-history-unknown to Points-dementia

{Weight loss} If (2weekweightloss>weight-threshold)
Add Points-weightloss to Points-depression
Add Points-weightloss to Points-dementia
If (2weekweightloss= unknown) {Add some weight}
Add Points-weightloss-unknown to Points-depression
Add Points-weightloss-unknown to Points-dementia

{Food Consumed} If (foodconsumed<food-threshold)
Add Points-food to Points-depression
Add Points-food to Points-dementia
If (foodconsumed= unknown) {add some weight}
Add Points-food-unknown to Points-depression
Add Points-food-unknown to Points-dementia

{Sleep Pattern} If (sleeppattern<acceptable-level)
Add Points-sleep to Points-depression
Add Points-sleep to Points-dementia
If (sleeppattern= unknown) {add some weight}
Add Points-sleep-unknown to Points-depression
Add Points-sleep-unknown to Points-dementia

{Behavior} If (behavior= violent)
Add Points-violent to Points-depression
Add Points-violent to Points-dementia
If (behavior= unknown)
{add some weight to cover uncertainty}
Add Points-violent-unknown to Points-depression
Add Points-violent-unknown to Points-dementia

{Overall Output } Context (history, weightloss, foodconsumed, sleeppattern, behavior), **Rank order** (depression, dementia)

Fig. 5 Context generation using weighted sum

V. MODELING AND RESULTS

The effectiveness of context generation can be measured by the overall probability of correct diagnosis expressed as

$$P_{CD} = (P_{CD\text{-}A}.\ P_A + P_{CD\text{-}B}.\ P_B)/\ (P_A + P_B) \quad \textbf{(1)}$$

Where P_A and P_B are the probabilities of illnesses A and B, respectively. $P_{CD\text{-}A}$ and $P_{CD\text{-}B}$ are the probabilities of correct diagnosis when illnesses are A and B, respectively.

$$P_{CD\text{-}A} = (\Sigma_{I=1}^{N}(W_I.P(C_I>T_I)) - \Sigma_{J=1}^{N}(W_J.P(C_J>T_J)))/\Sigma_{I=1}^{N}(W_I.P(C_I>T_I)) \quad \textbf{(2)}$$

Where W_I represents the weight given to attribute I and $P(C_I>T_I)$ is the probability that value of attribute I is more than the set threshold for attribute I. The choice of weights (or points) and setting of patient-specific thresholds will improve the overall probability of correct diagnosis from the scheme shown in Figure 5.

Mental health monitoring is likely to improve the quality of life improvement, but that is much harder to quantify. The effectiveness of mental health monitoring can be shown by measuring the number of additional days a patient is able to work, which would have been sick days without mental health monitoring. Thus the increased productivity (P_{INC}) per year can be simply expressed as

$$P_{INC} = A_{DW} * R_{DW} \quad \textbf{(3)}$$

Where A_{DW} and R_{DW} are additional days a patient is able to work due to the monitoring and rate per day of additional work, respectively. The total cost of monitoring per year (C_M) can be expressed as

$$C_M = C_{HW} + C_{NA} + C_{IM} + C_{HP} \quad \textbf{(4)}$$

Where C_{HW}, $C_{NA,}$ C_{IM} and C_{HP} represent the cost of hardware, network access, installation and management, and additional cost for healthcare professionals, respectively. The cost of hardware can be reduced by increasing its reusability and the cost of network access can be reduced by using lower cost networks such as wireless LANs. Further, the cost of installation and additional cost for healthcare professionals can be reduced to make the proposed MHM more affordable. The total saving per year (S_{PY}) can be simply computed as

$$S_{PY} = P_{INC} - C_M \quad \textbf{(5)}$$

Mental health monitoring is only effective if it leads to 10 or more days of work with average of $120/day productivity (Table III). Certainly, any lower improvement may still be cost effective for lower annual cost of monitoring.

TABLE III
COST SAVINGS DUE TO HIGHER PRODUCTIVITY

Cost of monitoring/year	Additional days of work	Increased productivity ($)	Savings/year per patient
$500	5	$600	$100
	10	$1200	$700
	50	$6000	$5500
$1000	5	$600	-$400
	10	$1200	$200
	50	$6000	$5000
$1500	5	$600	-$900
	10	$1200	-$300
	50	$6000	$4500

VI. CONCLUSION & FUTURE RESEARCH

The proposed framework for mental health monitoring includes a generalized MHM system and a context-aware implementation. Additionally, a model with several metrics for evaluation is presented. In future, the work will be applied to patients in remote areas and effectiveness of the proposed algorithm will be evaluated. It is expected that some more enhancements, including medication compliance, will be added in the proposed algorithm.

ACKNOWLEDGMENT

The author thanks Prof. Dan Robey for discussions on mental health monitoring in underserved and rural areas.

REFERENCES

[1] Mental Health: A Report of the Surgeon General, 1999 Website: http://mentalhealth.samhsa.gov/features/surgeongeneralreport/chapter1/sec1.asp#approach (accessed on July 21, 2008)

[2] AMA Concise Medical Encyclopedia (Medical Editor: Martin Lipsky), Random House Reference, 2006

[3] M. Ogawa and T. Togawa, "The concept of home health monitoring", In *Proc. of 5th International Workshop on Enterprise Networking and Computing in Healthcare Industry (Healthcom)*, 2003

[4] T. Tamura, T. Fujimoto, and T. Togawa, "Quantitative assessment of behavior in dementia patients by continuous physical activity monitoring", *In Proc. of IEEE Engineering in Medicine and Biology 19th Annual Conference (EMBC-1997)*

[5] WHO 2004 Report on Global Burden of Disease: http://www.who.int/healthinfo/global_burden_disease/GBD_report_2004update_part4.pdf

[6] H. Jimison, M. Pavel, J. McKanna and J. Pavel, "Unobtrusive monitoring of computer interactions to detect cognitive status in elders", *IEEE Trans. Inf. Technol. Biomed.* 8(3): 248-252, Sept. 2004

[7] U. Varshney, *Pervasive Healthcare Computing: EMR/EHR, Wireless and Health Monitoring.* Springer 2009, ch. 12 (http://www.springer.com/computer/hardware/book/978-1-4419-0214-6)

[8] E. Jovanov, A. O'Donnel, A. Morgan, B. Priddy, R. Hormigo, "Prolonged telemetric monitoring of heart rate variability using wireless intelligent sensors and a mobile gateway", In *Proc. Second Joint IEEE EMBS/BMES Conference*, 2002, 1875–1876

[9] C. Lin, M. Chiu, C. Hsiao, R. Lee, and Y. Tsai, "A wireless healthcare service system for elderly with dementia", *IEEE Trans. Inf. Technol. Biomed*, 10(2): 696-704, October 2006

[10] D. Stefanov, Z. Bien, and W. Bang, "The smart house for older persons and persons with physical disabilities: structure, technology, arrangements, and perspectives", *IEEE Trans Neural Syst Rehabil Eng* 12(2):228–250, June 2004

[11] J. Boger, J. Hoey, P. Poupart, C. Boutilier, G. Fernie, and A. Mihailidis, "A planning system based on markov decision processes to guide people with dementia through activities of daily living", *IEEE Trans. Inf. Technol. Biomed*. 10(2): 323-333, April 2006

[12] E. Ifeachor, G. Henderson, C. Goh, H. Wimalaratna, and N. Hudson, "Biopattern analysis and subject-specific diagnosis and care of dementia", *In proc. of 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference (EMBC-2005)*