MODELING AN AMBIENT AGENT TO SUPPORT DEPRESSION RELAPSE PREVENTION

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Abstract One of the challenges for the patients with a history of unipolar depression is to stay healthy throughout their lifetime. In principle, with more prior onset cases, it escalates the risk of the patients to fall into a relapse. In this paper, an ambient agent based model to support patients from relapse is presented. Theories and related works in depression relapse prevention provide a foundation for the formalization of the temporal properties to describe the model. This model was analyzed under several scenarios using simulation and automated verification.

Keywords - Ambient agent, unipolar depression relapse modelling, decision support model, temporal modelling.

I. INTRODUCTION

Depression carries in many terms and severity symptoms. Primarily, it can be triggered by life events and have an acute onset (within days or weeks). Despite of many pharmaceutical and holistic interventions, depression still has a high rate of relapse and recurrence [10]. Relapse is defined as "episode of major depressive disorder that occurs within six months after either response or remission (no longer meeting the depression criteria)"[11]. Reviewing studies of lifetime course of depression concluded that, the risk of repeated onset exceeds more than 60 percent for any individuals who have had one previous episode, and with the rate of 58 percent to strike back after 5 years of recovery [15][17]. Therefore, it is a need to have system that capable to support patient in a long term.

One of the main quests to have such a system is the ability to monitor patients' behaviours and changes using information related to them. To realize the quest, an ambient intelligent agent model was developed, and to be used to monitor patients' state over time. This kind of agent utilizes ambient sensor information about human, and their functioning to improve human's wellbeing. The agent model was designed using a set of dynamic properties, takes observations as input, and belief-desire-intention concept to determine its internal function and actions. Dynamic properties have been developed and formalized to model how humans are experiencing relapse. Using this information, the model was simulated and verified.

This paper is structured as follows. In the following, the model of an ambient agent is described. It covers several sub-models used as a building block of the model. Subsequently, the main concepts of this model are specified, and as a result, a formal presentation is designed. Later, results from simulation experiments are discussed and verified. Finally, a discussion concludes this paper.

II. OVERVIEW OF THE AMBIENT AGENT MODEL

A typical cause of relapse is a condition called the stressors. These stressors may derive from life, chronic, or daily events. The culmination of these factors will become overwhelming and leave a person feeling that they have lost control of their life. Such conditions can be observed through several ambient sensors and devices, namely; a medicine box that registers medication intake (MEMS) [6], a passive alcohol sensor [12], a mobile phone/ personal digital assistant (PDA) [5], and a blood volume pressure sensor [14][18]. The overall process of relapse monitoring has been modelled by using an ambient agent model. Four components are integrated to build the model, namely; domain model, belief base, analysis model and support model [2]. Figure 1 illustrates an overview of the entire ambient agent model.

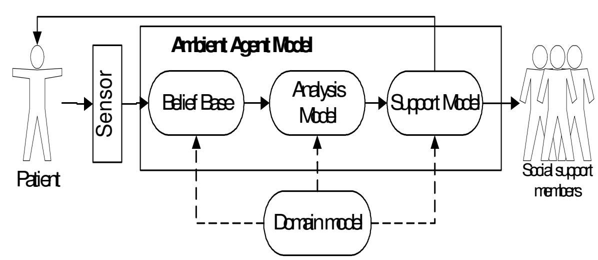


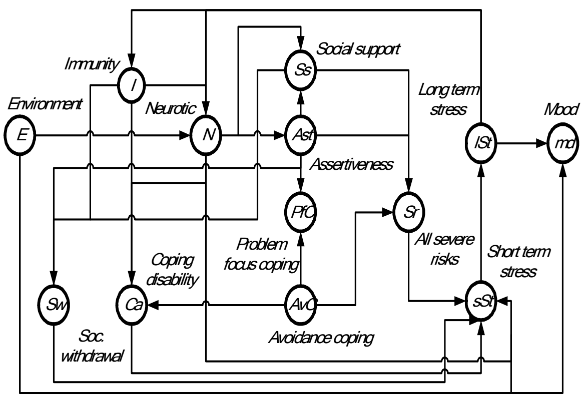
Figure 1. The Integration of the Components

From Figure 1, the solid arrow indicates information exchange between processes, and the dotted arrow represents the integration process of the domain model within the ambient agent models.

A. Domain Model

The observable factors that explain the progression of relapse are among key aspects to develop the domain model. This model uses the main factors of recurrence and relapse of depression as known from the literature. These factors are avoidant coping, social withdrawal, prolonged anxiety (neurotic), low in assertiveness, and high vulnerability towards relapse [7]. By coupling these concepts, a model to explain the phenomena of relapse was developed. Our previous work in human's relapse and recurrent model explains the temporal dynamics and interactions among those related factors existed prior to the onset [1]. Figure 2 summarizes the interaction among these factors used in the domain model.

Figure 2: Relationship of Factors Involved in Relapse



The simulation results have shown the model exhibits important patterns between the events and the course of relapse and recurrence. From several simulation runs, the domain model demonstrates three distinctive features in relapse / recurrence; (i) stressor events directly trigger the potential onset of relapse /recurrence, (ii) neuroticism escalates the effect of stressor events on the potential relapse / recurrence of a depression; and (iii) a combination of positive social support and coping skills will reduce the risk of having future relapse/recurrence [1][10][13][17]. In order to implement related concepts from the domain model, three sub-models were designed within an ambient agent model, namely; belief base, analysis, and support model. In this model, desire to reduce the relapse is added as a desire refinement, to support the decision making process during relapse prevention. It derives another desire to perform intention to support patient. The relationship between these two desires can be described as

∀K:TASK, ∀X:AGENT
desire(X, reduced(risk_relapse)) ↠ desire(K)

Furthermore, during this process, the agent considers temporal, causal, and other relation between the observable events to recognize the most suitable action, which describes possible solution for state of the patient at a specific time. The details of these sub-models can be found in [2].

III. FORMALIZING DYNAMIC PROPERTIES

To specify properties on dynamics relationship, the ontology of the model is designed using predicate calculus. For example, any agent ability to observe the frequency level of pill intake can be expressed as observed(X:AGENT, pill_intake,(F:FREQ_LEVEL)).

Ontology for Agent's Observation: Observation using several sensors (input from patient-world interaction). The agent observes human's condition through pill intake activities, alcohol compound in a blood stream, blood pressure level, phone usages, and social interaction with the social group.

observed(X:AGENT, pill_intake(F:FREQ_LEVEL))
observed(:X:AGENT , alcohol_level(L:LEVEL))
observed(X:X:AGENT , BVP_level (L:LEVEL))
observed(X:AGENT, phone_usage(T:TYPE))
observed(X:AGENT, social_activity(T:TYPE))

Ontology for Belief Base: *Basic belief* (generated belief after several observations on pill intake, alcohol level reading, social activities, phone usage, and blood volume pressure reading)

belief(X:AGENT, pill_intake(F:FREQ_LEVEL))
belief(:X:AGENT , alcohol_level(L:LEVEL))
belief(X:X:AGENT , BVP_level (L:LEVEL))
belief(X:AGENT, phone_usage(T:TYPE))
belief(X:AGENT, social_activity(T:TYPE))

Derived belief (belief on substance abuse, avoidant coping, neurotic, social support, immunity and assertiveness)

belief(X:AGENT, sub_abuse(L:LEVEL))
belief(X:AGENT , avoidant_coping(L:LEVEL)
belief(X:AGENT , neurotic(L:LEVEL))
belief(X:AGENT , social_support(T:TYPE))
belief(X:AGENT , immunity(L:LEVEL))
belief(X:AGENT , assertiveness(L:LEVEL))

Ontology for Analysis Model: There are three levels of analysis used; evaluation on coping skills, social withdrawal, and severe risk factors. These distinctive features provide important information to execute a specific action in the support model.

assessment (X:AGENT, coping_skill(L:LEVEL))
assessment (X:AGENT, social_interaction(L:LEVEL))
assessment(X:AGENT, all_factors(L:LEVEL))
prediction(X:AGENT , stage(C:COND, T:TYPE))

Ontology for Support Model: Two main actions are used to intervene the risk of relapse namely; notify and advice. The BDI approach regulates action selection process (internal processing) [9]. An action to be taken by an ambient agent is represented using *performed* as its predicate.

belief(X:AGENT, seek(K:TASK)
desire(X:AGENT, improved(K:TASK))
desire(X:AGENT, reduced(C:COND)
intention(X:AGENT , advice(K:TASK))
intention(X:AGENT, notify(R:ROLE))
performed(X:AGENT , advice(K:TASK))
performed(X:AGENT, notify(C:COND, R: ROLE))
belief(X:AGENT, stage(C:COND, T:TYPE)

The formalization of some properties makes use of sorts. These sorts are presented in Table 1.

Table 1. Sort Used

Sort	Elements
LEVEL	{low, medium, high}
TYPE	{positive, negative}
FREQ_LEVEL	{normal, not_taken, overdose}
TASK	{avoid_ substance_ abuse, social_activities, relaxation_activities, coping_ skills, meet _doctor_therapist}
ROLE	{patient, friends_ family, doctor_therapist}
AGENT	{low, medium, high}
COND	{risk_relapse, anxiety, healthy}

In order to specify simulation model, a temporal specification language has been used. This language called as LEADSTO enables one to model direct temporal relationship between two state properties (dynamic properties). Consider the format of $\alpha \twoheadrightarrow_{e,f,g,h} \beta$, where α and β are state properties in form of a conjunction of atoms (conjunction of literals) or negations of atoms, and e,f,g,h represents non-negative real numbers. This format can be interpreted as follows;

> If state α holds for a certain time interval with duration g, after some delay (between e and f), state property β will hold a certain time interval of length h.

Here, atomic state properties can have a qualitative, logical format to represent certain observed conditions. In addition, this representation also holds a temporal traceγ, denoted by $\gamma \models \alpha \twoheadrightarrow_{e,f,g,h} \beta$, if

$\forall$t1[$\forall$t1[t1- g $\leq$ t < t1 $\Rightarrow$ α holds in γ at time t]
$\Rightarrow$ $\exists$d [e $\leq$ d $\leq$ f &
$\forall$t' [t1+ d $\leq$ t'< t1 + d+ h] $\Rightarrow$ β holds in γ at time t']

For a more detailed discussion of this language, see [3]. It is worth to mention in this paper, LEADSTO is mainly used as a modelling instrument. It also possible to be implemented with any related tool.

Temporal Specification of the Ambient Agent

The temporal rules specification of an ambient agent has been specified using the ontology. Each specification is designed to provide a set of knowledge for an ambient agent to reason with. To utilize the specification, a forward method for belief generation is used. This way of reasoning allows the time sequence and causality, originated from beliefs about related properties at certain previous time point, and new beliefs about properties at later time points. The ambient agent functionality is described by three actions; belief generation in belief base, evaluation of risk, and action selection for the support. For example, in a social withdrawal case, the ambient agent observes the patient's condition and generates its monitoring beliefs at the belief base. In belief base, these properties are identical with the observed one. It can be generalized as; IF ambient agent X observes Y, then ambient agent X will believe Y.

observed(X, Y) $\twoheadrightarrow$ belief(X,Y)

The following properties show several temporal specifications in social withdrawal condition.

BEL4: Generating basic belief on phone/PDA usage

When the ambient agent observes there is no phone/PDA usage, then the agent beliefs that a patient is not using phone/PDA to communicate with the others.

observed(agent, phone_usage(negative) $\twoheadrightarrow$ belief(agent, phone_usage(negative))

DB1: Derived belief on social support from the phone usage belief

If the ambient agent believes that there is no phone usage then the agent will believe there is no social interaction between social support network members.

belief(agent, phone_usage(negative))
$\twoheadrightarrow$ belief(agent, social_support(negative))

Then, in order to reason about the observed belief, this information is interpreted in the analysis model.

AE2: Evaluation on social withdrawal condition

If it is believed that patient is not interacting with any social network support members, and having difficulty to control anger and it is believed that patient is vulnerable for the future onset then the agent concludes that the condition of the patient as having social withdrawal.

belief(agent, social_support(negative)) $\wedge$ belief(agent, assertiveness(low)) $\wedge$ belief(agent, immunity(low))
$\twoheadrightarrow$ assessment(agent, social_interaction(low))

PR3: Predicting the risk of relapse from social withdrawal condition

If the patient is having social withdrawal then the ambient agent will assesses the patient as having potential risk of relapse.

assessment(agent, social_interaction(low))
$\twoheadrightarrow$ prediction(agent, stage(risk_relapse, positive))

Finally, the ambient agent will utilize specified temporal rules in the support model to take appropriate actions.

BEL2: Belief on relapse

When the ambient agent predicts the patient is having a risk in relapse, then the ambient agent will believe the patient is in the risk of relapse.

prediction(agent, stage(risk_relapse, positive))
$\twoheadrightarrow$belief(agent, stage(risk_relapse, positive))

ACT2: Action to notify social support networks

When the ambient agent believes the patient in the risk of relapse then the ambient agent will notify all friends and family within social support network.

belief(agent, stage(risk_relapse, positive)) $\twoheadrightarrow$
performed(agent, notify(risk_relapse, friends_family))

ACP1: Action to notify the patient
When the ambient agent believes the patient in the risk of relapse then the ambient agent will notify the patient.
belief(agent, stage(risk_relapse, positive))
↠ performed(agent, notify(risk_relapse, patient))

DES2: Desire to improve social interaction
If the ambient agent assesses the patient is having social withdrawal then the ambient agent will desire to improve patient's social interaction by advising the patient about suitable social activities.
assessment(agent, social_interaction(low)) ∧ desire(agent, reduced(risk_relapse))
↠ desire(agent, improved(social _activities))

INT3: Intention to advice on social interaction
When the ambient agent desires to improve patient's social interaction through social activities and ambient agent believes there is no social interaction between a patient and social support network members, then ambient agent will have an intention to advice patient on suitable social activities.
desire(agent, improved(social _activities)) ∧
belief(agent, social_support(negative))
↠ intention(agent , advice(social_activities))

ACT6: Action to advice on social interaction activities
When the ambient agent intends to advice the patient regarding to social activities to the patient, then the ambient agent will advice the patient about those social activities.
intention(agent , advice(social_activities))
↠performed(agent , advice(social_ activities))

IV. SIMULATION RESULTS

Based on the proposed model, using the specified temporal rules to determine the stage of patient, several simulations have been performed. For this paper, three examples of simulation runs were chosen. In the figures below, timeline is shown on the horizontal axis, the state properties are on the vertical axis and a dark box indicates that a state property is true.

Simulation # 1: Social Withdrawal
This condition occurs when the ambient agent observes no activities in social interaction, low in assertiveness, and highly vulnerable towards future onset. The patient is highly advised to engage social interaction with others [16]. Having this in motion, social support network members will be informed by an ambient agent (see Figure 7).

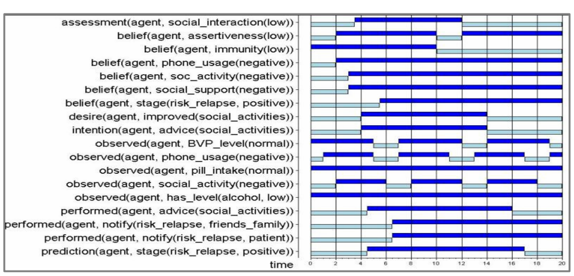


Figure 7. Simulation Trace in Social Withdrawal

Simulation #2: Deficiencies in Coping Skills
In this simulation, the ambient agent observes several risks, such as; a high blood volume pressure, high alcohol level, and overdose pill intake. Based on this, the agent assesses that the person is facing a risk of relapse, subject to coping skills problem [12]. Therefore, the agent desires to give advice to improve coping skills, specifically to reduce anxiety and later to eliminate substance abuse are translated into intentions. Prior to this, the beliefs about the conditions must hold true. Figure 8 depicts the simulation trace of this condition.

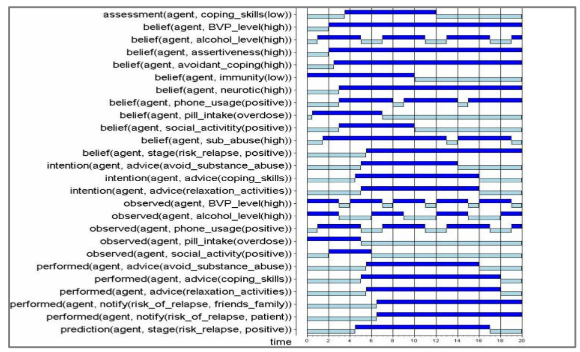


Figure 8. Simulation Trace in Coping Skills Deficiencies

Simulation # 3: Severe Risk Factors
The severe risk factors occur when all observed risk factor features show a positive contribution towards the future onset. Normally, seeking medical advice is the only best option [17]. When an ambient agent evaluates a patient is having all severe risk factors, the doctor or the therapist will be notified. The patient will receive a notification to seek for medical advice. The result of this condition is shown in Figure 9.

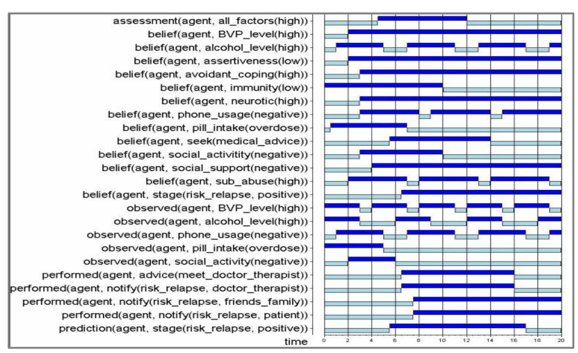


Figure 9. Simulation Trace for All Severe Risk Factors

V. VERIFICATION OF THE MODEL

This section deals with the verification of relevant dynamic properties of the cases considered in an ambient agent model. It is important to verify whether the model produces results coherence with the literatures. It deals with building the model *right*. Several properties have been identified from related works in relapse management. The Temporal Trace Langue (TTL) is used to perform an automated verification of specified properties against generated traces. This language allows formal specification and analysis of dynamic properties; it is either a qualitative or a quantitative representation [3].

TTL is designed on atoms, to represent the states, traces, and time properties. This relationship can be presented as a state(γ, t) |= p, means that state property p is true the state of trace at time point t [4]. It is also comparable to the *Holds*-predicate in the Situation Calculus. Based on that concept, dynamic properties can be formulated using a sorted first-order predicate logic (*FOPL*) approach.

VP1: Advice to avoid substance abuse during the risk of relapse

When a patient is believed to have a problem in substance abuse, prolong high neurotic level and vulnerable towards relapse (low in immunity) then the ambient agent provides advice to avoid substance abuse.

∀γ:TRACE, t:TIME
[state (γ, t) |= belief (agent, sub_abuse(high) ∧
state (γ, t) |= belief(agent , neurotic(high)) ∧
state (γ, t) |= belief (agent, immunity(low))]
⇒ ∃t':TIME > t:TIME[state(γ, t') |=performed (agent, advice(avoid_ substance_ abuse)]

Substance abuse advice needs to be delivered if the patients are showing the risk of relapse, and with the combination of substance abuse problem, vulnerable to the onset, and prolong exposure to the anxiety [12]. It is vital since by prolong exposure towards substance abuse will increase the risk of future onset [8].

VP2: Warn for medical help if all risk conditions have been observed

When the doctor or therapist has been informed, the patient have already had all severe risk factors observed [8].

∀γ: TRACE, t:TIME
[state(γ, t) |=performed (agent, notify(risk_relapse, doctor_therapist)]
⇒ ∃t':TIME < t:TIME
[state (γ, t') |= belief(agent, sub_abuse(high) ∧
state (γ, t') |= belief(agent, neurotic(high) ∧
state (γ, t') |= belief (agent, immunity(low)) ∧
state (γ, t') |= belief (agent,assertiveness(low)) ∧
state (γ, t') |= belief (agent,social_support(negative))]

VP3: Social support networks as a buffer for negative life events

When the ambient agent predicts a patient is having a risk in relapse then the ambient agent sends a notification message to related friends and family within the social support network members.

∀γ: TRACE, t:TIME
state(γ, t) |= prediction(agent, stage(risk_relapse, positive)
⇒ ∃t':TIME > t:TIME [state(γ, t') |=performed (agent, notify(risk_relapse, friends_family))]

Friends and family within social support networks need to be informed if the patient is developing the risk of relapse in future. Ability to have social support is one of the crucial elements to reduce the risk of relapse [16] [17].

VP4: Relaxation training to reduce high comorbidity between anxiety and future onset

If the ambient agent observes a patient is having a high reading in blood volume pressure then the ambient agent provides advice on relaxation activities

∀γ: TRACE, t:TIME
state (γ, t) |= observed(agent , BVP_level (high))
⇒ ∃t':TIME > t:TIME [state(γ, t') |=performed (agent, advice(relaxation_activities))]

Anxiety can be reduced through a series of relaxation activities. By reducing the level of anxiety (neurotic), it will deplete the risk of having a relapse [17].

VP5: Involvement in several social activities to reduce the risk of relapse in the case of social withdrawal

When the ambient agent evaluates a patient is having social withdrawal and the ambient agent believes that a patient is having no social support then the ambient agent will provide advice to engage with suitable social activities.

∀γ: TRACE, t:TIME
[state(γ, t) |= assessment(agent,social_interaction(low)) ∧
state(γ, t) |= beliefl(agent, social_support(negative))]
⇒ ∃t':TIME > t:TIME [state(γ, t') |=performed (agent, advice(social_activities))]

Deficits in social activities increase the chance of relapse. Positive social activities mitigate between stressful life events and onset [16].

VI. CONCLUSION

In this paper, the model of an ambient agent to monitor relapse in depression is introduced. Within this ambient agent model, all-sub models are integrated to provide basic understanding for the agent to perform certain tasks (i.e; monitoring patient's conditions, evaluating the risk, or deciding actions) in order to sustain patients' wellbeing (by eliminating risk of developing another depression). The integration takes place by encapsulating domain model in all sub-models. A set of formal temporal properties are derived to allow intelligent reasoning to take place. From this formal model, several simulation runs were executed using LEADSTO language. The simulation results have been verified based on several properties using TTL environment. It was shown that the ambient agent model indeed through simulation is potentially be used to provide a support for patients. In addition, to conduct thorough evaluation and fine-tuning of the proposed model, future work will focus on generalizing the proposed model to an ambient agent based generic model for stress-risk evaluation and support in several related domains.

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