DESIGN AND ANALYSIS OF AN AMBIENT INTELLIGENT SYSTEM SUPPORTING DEPRESSION THERAPY

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Abstract: This paper addresses the design of an ambient intelligent system to support humans that follow "activity scheduling" therapy to recover from a uni-polar depression. The system consists of a personalized website and a mobile-phone based reporting a reminder system. To analyze the system, a previously developed dynamic model is used to simulate a client. It is illustrated by interactive simulation that the system is more effective than the plain internet-based therapy that is offered at the moment. In continuation of the work described in this paper a clinical trial is planned in the first half of 2009.

1 INTRODUCTION

A clinical depression is one of the most prominent disturbances in mood. It is a common psychiatric disorder, affecting about 7–18% of the people at least once in their lives. In the USA, the prevalence is approximately 14 million adults per year. Symptoms of a depression are a deep feeling of sadness, and a noticeable loss of interest or pleasure in favorite activities. There is not one specific cause of a depression, most experts believe that both biological and psychological factors play a role.

A variety of therapies is available to intervene within a depression, such as cognitive therapy and activity scheduling (Lewinsohn, Youngren and Grosscop, 1979). The basis for activity scheduling is that a depression can be treated by increasing the positive reinforcement through increasing the quantity and quality of activities. Recently, it is shown that activity scheduling interventions offered via the Internet are very effective (Spek et al, 2007). The problem with such Internet inventions is however that the patient is not continuously supported in the therapy. Having this more continuous support might lead to a more effective intervention. Therefore, this paper aims at given the patient support via the mobile phone. The advantage of using a mobile phone is that patients typically carry this device around with them most of the time. The support model is specified in a formal fashion to allow for logical simulation. In order to evaluate the effectiveness of the continuous support, a computational model (cf. Both, Hoogendoorn, Klein & Treur, 2008) of mood and depression is used to investigate the influence of the support upon these factors.

This paper is organized as follows. Section 2, first summarizes the dynamic model for depression adopted from (Both et.al., 2008). Section 3 briefly describes the idea of activity scheduling. In the next section, the ambient intelligent system model to support activity scheduling is described. In Section 5, a simulation of two different scenarios based on the dynamic client model is explained. This shows that, according to the models, the system is more effective than plain internet-based support. Finally, Section 6 concludes the paper and describes the clinical trial that to evaluate the system in practice that is planned for the second half of 2008.

2 DYNAMIC MODEL OF DEPRESSION

Figure 1 gives a conceptual overview of the model developed in (Both et.al., 2008), which is based on the major theories about a uni-polar depression. In the model, it is assumed that every situation has an emotional value, which represents the extent to which a situation is experienced as something positive.

The *objective emotional value of situation* (OEVS) represents how an average person would perceive the situation. A situation can be an event or series of events one has no control over, or that are chosen or influenced by the person. The *subjective emotional value of situation* (SEVS) can differ from

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OEVS when the *thoughts* of the person are more positive or more negative than average. Negative thoughts will cause the SEVS to be lower than OEVS, which is often the case with a depression. How one perceives the situation (SEVS) influences the *mood* one is in and the *thoughts* one has. When the person is in a positive situation, mood level and thoughts will increase. For example, attending a birthday party, which is usually a positive experience, causes a better mood and more positive thoughts. In contrast, an argument with a close friend has a low emotional value and causes a bad mood and negative thoughts. By changing or choosing a situation, one can influence their own mood level (e.g. choosing to go to the birthday party when one feels down increases the mood level). The complex notion of mood is represented by the simplified concept *mood level*, ranging from low corresponding to a bad mood to high corresponding to a good mood. The mood level influences and is influenced by *thoughts*. Positive thinking has a positive effect on the mood and vice versa. The mood level someone strives for, whether conscious or unconscious, is represented by *prospected mood level*. This notion is split into a *long term prospected mood level*, an evolutionary drive to be in a good mood, and a *short term prospected mood level*, representing a temporary prospect when mood level is far from the prospected mood level. The node *sensitivity* represents the ability to change or choose situations in order to bring mood level closer to prospected mood level. A high sensitivity means that someone's behavior is very much affected by thoughts and mood, while a low sensitivity means that someone is very unresponsive. The level of sensitivity itself is influenced by mood level and thoughts. A low mood level and negative thoughts can decrease the sensitivity and a high mood level and positive thoughts can increase the sensitivity. Mood level, prospected mood level and sensitivity together influence *OEVS* by choosing or changing a situation.

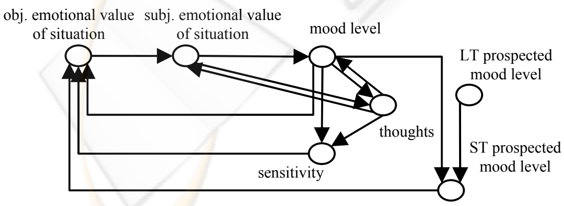

Figure 1: Model of mood dynamics.

The new value of a node is determined by preceding nodes and the previous value of that node. Decay factors determine how fast the previous value of the node decays. For the entire model there are two decay factors: *diatheses* for downward regulation and *coping* for upward regulation. The term *diatheses* represents the vulnerability one has for developing a depression. The term *coping* represents the skills one has to deal with negative moods and situations. A person with very low diatheses will probably never get a depression, because mood, thoughts and sensitivity will go down very slowly with a negative event. That person is therefore always capable of choosing situations that have a positive influence on his/her mood level and emotions. High diatheses and low coping skills will cause a person to get a depression very easily when a negative event occurs, because mood, thoughts and sensitivity will decrease fast. It will be very difficult to climb out of a depression: the upward regulation of mood, thoughts and sensitivity will go very slow.

3 ACTIVITY SCHEDULING

Activity scheduling (AS, also called behavioral activation) is an intervention for clinical depression based on a theory by Lewinsohn, Youngren & Grosscop (1979) who say that a low rate of behavior (often caused by inadequate social skills) is the essence of a depression and the cause of all other symptoms. Part of his theory is the hypothesis that there is a causal relationship between lack of positive reinforcement from the environment and the depression. A depression can be treated by increasing the positive reinforcement through increasing the quantity and quality of (social) activities. Many studies have shown that this type of intervention works just as well as or even better than other popular treatments, such as cognitive (behavior) therapy (CT or CBT) and antidepressant medication (Dimidjian et al, 2006; Jacobson et al, 1996; Iqbal & Bassett, 2008). Recently, it is shown that interventions offered via the internet are very effective (Christensen et al, 2004; Proudfoot, 2004, Andersson et al, 2005, Spek et al, 2007).

There are two stages in AS: the first stage is observing that pleasant activities and a good mood come together by writing down all pleasant activities and mood level. Usually, the more pleasant activities have been performed, the better the mood has been. The second stage is changing the activity schedule so that the patient participates in more pleasant activities with the goal of increasing the mood level. By doing more pleasant activities in stage 2, the mood increases on a short term, and by learning that pleasant activities influence mood level positively, patients are more capable of dealing with future situations. In our model of mood and depression, these effects can be seen as a positive influence on

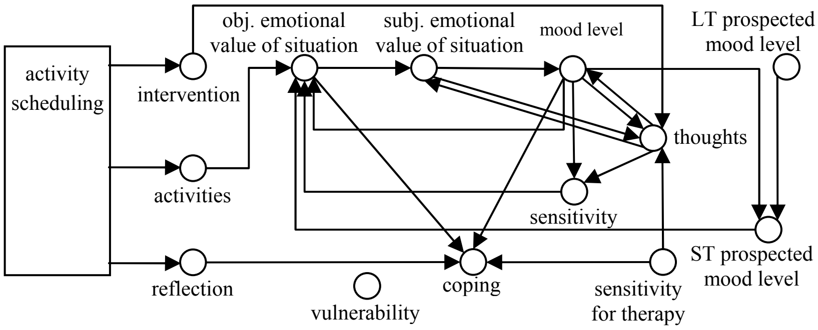

Figure 2: Effect of activity scheduling therapy in the depression model.

OEVS (increasing the number of positive activities), thoughts and coping (learning that pleasant activities lead to a better mood on short term and long term). By first showing the patient that positive situations increase mood level, negative thoughts about self, others and world will decrease. This will result in a higher sensitivity: the patient is more capable of choosing a situation that increases the mood level. When the patient is more able to choose positive situations both by an increased sensitivity and by stimulation from the AS intervention, the patient will perceive the situation better and the mood level will go up.

There may also be an initial positive influence on the short-term prospected mood level when a person with depression seeks counseling. This may explain the placebo effect of antidepressant medication and the 'fact' that people on a waiting list improve.

The influence of the activity scheduling occurs on three places within the model. First of all, the planning of *activities* can be used to determine the new OEVS. Secondly, the fact that the patient is undergoing the activity therapy will influence the thoughts in a positive way (*intervention*). Finally, activity scheduling makes the patient aware of the relationship between OEVS and the mood level resulting in better coping skills (*reflection*). Below, in Figure 2, the graphical representation is shown. The sensitivity for therapy influences the impact of

$$coping(t+\Delta t) = coping(t) + (reflection(t) \cdot sensitivity\_for\_therapy(t) \cdot (1 - |oevs(t) - mood(t)|) \cdot (1 - coping(t)) \cdot \Delta t$$

AS on thoughts and coping.

In the model coping is calculated as follows. The idea behind the formula is that the patient is learning the relationship between mood and the OEVS. This means that the patient will learn faster in case the two are closer. Furthermore, the more sensitive the patient is for therapy, the faster this learning process will go. For the calculation of thoughts the following formula is used, which takes the positive influence of the therapy into account:

In case the condition holds, the former is true, otherwise the latter. The formula specifies that in

$$thoughts(t+\Delta t) = \begin{cases} th(t) + coping \cdot (\phi - th(t)) + (1 - (th(t) + coping \cdot (\phi - th(t)))) \cdot I \cdot \Delta t & \phi >= th(t) \\ th(t) + diatheses \cdot (\phi - th(t)) + (1 - (th(t) + diatheses \cdot (\phi - th(t)))) \cdot I \cdot \Delta t & \phi < th(t) \end{cases}$$

$$\phi = sevs(t) \cdot w_{sevs\_thoughts} + mood(t) \cdot w_{mood\_thoughts}$$

$$I = intervention(t) \cdot sensitivity\_for\_therapy(t)$$

case the activity scheduling therapy is undergone (i.e. intervention(t) = 1) the thoughts are positively influenced by multiplying the difference between "optimal" thoughts (i.e. 1) and actual thoughts (i.e. the current thoughts plus the difference caused by the other states) with the sensitivity for the therapy.

The emotional value of a situation is determined by the current and prospected mood levels, the sensitivity for choosing optimal situations and the activities done according to the AS therapy. When a pleasant activity is done, the formula for OEVS is as follows.

where *w1* is the influence of the ability to choose a

$$oevs(t+\Delta t) = w1 \cdot (oevs(t) - sensitivity(t) \cdot \varphi \cdot \Delta t) + w2 \cdot activities(t)$$

$$\varphi = \begin{cases} oevs(t) \cdot \delta_{mood} & \delta_{mood} >= 0 \\ (1 - oevs(t)) \cdot \delta_{mood} & \delta_{mood} < 0 \end{cases}$$

$$\delta_{mood} = mood(t) - \beta \cdot lt\_prosp\_mood$$

good situation, and *w2* is the influence of the activities planned following the AS therapy.

4 DESIGN OF THE AMBIENT ASSISTIVE SYSTEM

The activity scheduling therapy is provided in different ways, for example with support of a therapist (Lewinsohn et al, 1986), via self-help books (also called bibliotherapy, e.g. Clarke 1990) and as internet-based course.

4.1 Overall System Design

The system presented in this paper functions as a combination of an internet-based course and the use of smartphones: a patient plans his course via the internet, where a server maintains personal data of the patient and keeps track of his progress and status; based on this status, the patient receives personalized support via a smartphone.

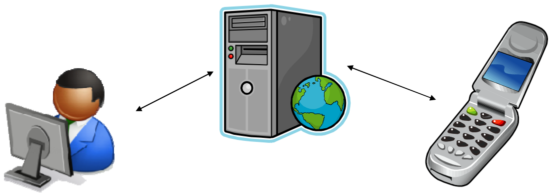

Figure 3: Combined smartphone and internet support.

The basic ingredients of the internet course are keeping a regular diary of activities and the perceived mood, and planning and performing pleasant activities, possibly supported by small rewards. The assistive system helps with both tasks. At the start of the course, the patient first has to define his personal ordering of pleasant activities and a list of rewards (such as “buying my favorite magazine). For the first task of the course (keeping the diary), the patient has to register every day the number of pleasant activities he has undertaken and a grade for his perceived mood. In the internet-only version of the course, he has to do this every day behind a computer. With the assistive system, he will be able to report this via a simple interface on a smartphone. For this, the phone shows the pre-defined list of pleasant activities and allows the user to check the activities that he has undertaken or add a new pleasant activity. In addition, the user is asked to rate his own mood on a scale from 1 to 10. All provided information is then stored in the personal profile at the web server. Because of the mobility of the phone, the user can choose to report his activities and mood on a more frequent basis than the per day basis in the internet-only version, e.g. per morning, afternoon and evening. As a consequence, the system will result in a more fine-grained registration of the mood, and therefore probably help people to recognize the relation between pleasant activities and mood earlier.

In the second phase of the course, the patient has to plan activities. This is normally done via the website. In this phase, the system can support by sending reminders to the phone before the planned start of an activity. It is up to the user to define for which type of activity reminders are desired. For example, activities that require a long preparation do not benefit from short-term reminders. The reminders could stimulate people to better keep to their planning and thus doing more pleasant activities. After a planned activity, the system will ask the user whether he indeed undertook the activity, how pleasant it was, and how he feels. The system will give immediate positive feedback if the mood is higher than before, e.g. ‘good to see that you feel better now after playing tennis than you felt this morning’. This again helps the patient to see the relation between activities and mood. In addition, the system will suggest to effectuate some of the rewards if some progress has been made (e.g. a number of pleasant activities have been performed).

After a few days of doing activities, the system can analyze the activities and mood levels and give personalized advice about how to proceed. For example: ‘activity x was not as pleasant as you thought, maybe you shouldn’t schedule it for next week’, or ‘you have done many expensive activities, is that why your mood is not improving?’.

The internet is the main interface that is used for the longer term feedback. Via his personal website, the user can consult tables and graphs that show the relation between the number of activities undertaken and the reported mood. Also, the long term development of the mood level can be shown. The user can also request this information via the smartphone.

4.2 System Rules

Phase 1

1. if pre-set time interval has passed, prompt user via smartphone to check the activities that have been performed
   ∀I, I2:integer
   frequency_set_for_first_stage(I) ∧
   current_time(I2) ∧ (I2 mod I = 0) →
   output(check_activities_please)
2. if pre-set time interval has passed, prompt user via smartphone to report mood level
   ∀I, I2:integer
   frequency_set_for_first_stage(I) ∧
   current_time(I2) ∧ (I2 mod I = 0) →
   output(score_mood_level_please)

Phase 2

3. if it is less than X minutes before a planned activity and the type of activity is set to receive a reminder, send a reminder to the smartphone
   ∀I, I2:integer, A:ACTIVITY
   activity_scheduled_begin_time(A, I) ∧
   reminder_active(A) ∧ current_time(I2) ∧
   I2 = I – X →
   output(do_not_forget_to_perform_activity, A)
4. if X minutes have been passed after a planned activity, ask the user whether the activity has been performed
   ∀I, I2:integer, A:ACTIVITY
   activity_scheduled_end_time(A, I) ∧

current_time(I2) ∧ I2 = I + X →
output(did_you_perform_actitvity, A)

5. if the activity has been performed, prompt the user to rate the pleasantness of the activity and his mood
∀A:ACTIVITY
input(performed_activty, A, yes) →
output(score_mood_level_please)
6. if the reported mood level is higher than the previously reported mood level, and the activity was pleasant, give positive feedback message
∀I, I2:integer
input(mood_level, I) ∧ previous_input(mood_level, I2) ∧
I > I2 ∧ I > BOUNDRY_POSITIVE_MOOD
→ output(well_done_progress_can_be_seen)
7. if the first pleasant activity during the course has been performed, suggest a reward from the predefined list via the smartphone
∀I, I2:integer, A, A2:ACTIVITY, R:REWARD
input(performedactivity, A, yes) ∧
previous_input(performed_activity, A2, no) ∧
suitable_reward(A, R)
→ output(well_done_reward_yourself, R)

4.3 Example System Simulation

The intervention as described in the previous section has been implemented in a simulation environment, i.e. LEADSTO (Bosse et al,, 2007). Using this environment, we mimicked the functioning of the cell phone system in different scenarios. The results of using the cell phone system in the first stage of the activity scheduling therapy are shown in Figure 4. In the figure, the x-axis represents time (in hours) whereas the y-axis indicates the atoms that occur over time. In the figure a dark box indicates that the atom is true at a particular time point, whereas a grey box indicates it is false. It can be seen that a frequency is initially set by the patient to receive messages every five hours:

input(frequency_of_first_stage, 5)

As a result, the patient receives two messages asking him to check the activities and the mood level:

output(score_mood_level_please)
output(check_activities_please)

Thereafter the patient responds with the answer that the mood level is 2, and one activity which has been performed, namely walking in the park:

input(mood_level, 2)
input(performed_activity, walk_in_the_park, yes)

Of course, the process continues every five hours, but these have been left out for the sake of clarity.

The output of the support system for the second run is shown in Figure 5. It can be seen that the patient inputs the schedule for the day, including a period of running from 15:00 till 16:00, going out for dinner between 19:00 and 20:00 and going to a birthday of a friend between 23:00 and 24:00:

input (activity_scheduled_begin_time (go_running, 15))
input (activity_scheduled_end_time(go_running, 16))
input (activity_scheduled_begin_time
(go_out_for_dinner,19))
input(activity_scheduled_end_time(go_out_for_dinner,20))
input (activity_scheduled_begin_time
(go_to_friends_birthday, 23))
input (activity_scheduled_end_time
(go_to_friends_birthday, 24))

Furthermore, reminders are set active for all activities except for the running activity. After the running activity schedule indicates the activity has ended, the cell phone system asks the patient whether the activity has been performed:

output(did_you_perform_activity, go_running)

The patient answers that this activity has not been performed. Just before the going out for dinner activity has been scheduled the cell phone sends a warning, since warnings are enabled for this activity:

output(do_no_forget_to_perform_activity,
go_out_for_dinner)

After the activity is finished the cell phone asks whether the activity has been performed, which is indeed the case in the trace. As a result, the cell phone sends an encouraging message (since previously a scheduled activity was not performed):

output(well_done_reward_yourself_with,
buy_nice_present_for_yourself)

Moreover, a question is posed what the mood level of the patient is, which is in this case ranked as 5:

input(mood_level, 5)

For the final activity scheduled for the day, a reminder is sent again. After the activity has been scheduled, a question is posed by the cell phone again whether the activity has been performed. This is indeed the case, resulting in the used scoring the mood level which is now a 7. Since the mood has increased compared to the previous mood level, the cell phone sends a message:

output(well_done_progress_can_be_seen)

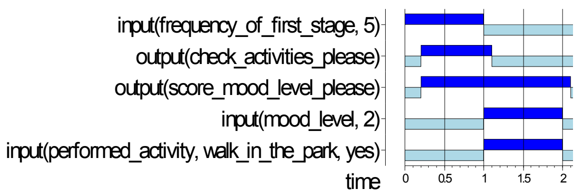

Figure 4: Results using the cell phone system in phase one.

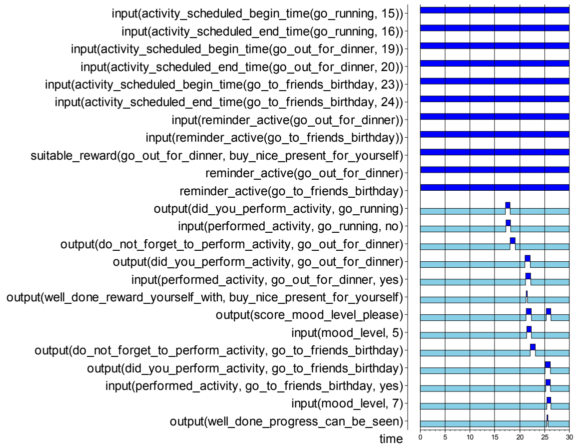

Figure 5: Results using the cell phone system in phase 2.

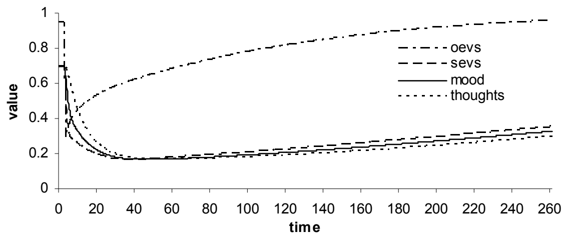

Figure 6: Unhealthy person, 1 negative event, no therapy.

5 SIMULATION-BASED ANALYSIS OF THE SYSTEM

To analyze the system, a number of system simulations have been performed in interaction with a simulated client. In this interactive simulation processes, the simulation for the system is based on the model description in Section 4, the simulation of the client is based on the mood dynamics model described in Section 3. A selection of the results is shown in Figures 6 to 9. These results show how the supporting system has a substantial impact on the course of the depression.

All figures show the simulated mood level (continuous line) of a patient that has relative high vulnerability and low coping skills. In addition, the average objective emotional value of all events (oevs) is shown, the perceived emotional value of the situation (sevs), and the simulated thoughts level.

At time point 3 an event with a negative emotional value occurs. As can be seen in all figures, this event causes a depression in the patient: the mood-level decreases. In Figure 6, which represents a patient that does not receive therapy, one can see that the average objective emotional values of the situations increases, but that this is not directly followed by the mood-level of the patient.

Figure 7 represents a patient (with otherwise the same conditions as in the patient represented by Figure 6) who receives web-based activity scheduling therapy. The figure clearly shows that the therapy helps to recover from the depression. The capricious line for the objective emotional value is caused by the pleasant activities that are undertaken by the patient, stimulated by the therapy. In addition, although not directly visible in the graph, the interventions in the therapy have a positive effect on the thoughts, and the reflection about the relation between activities and the perceived emotional value of the situation causes an increase in of the coping skills.

Finally, Figure 8 shows a representation of the same patient that follows the same therapy, but now supported by the ambient assistive system. The difference with the previous scenario is that the system, following the rules described in Section 4, helps the patient to keep to his own schedule (thus increasing the number of pleasant activities) and is giving positive feedback (thus further increasing the

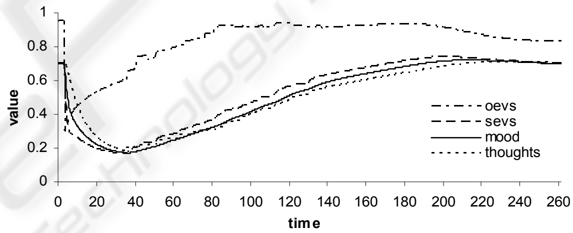

Figure 7: Unhealthy person, 1 negative event, web-based activity scheduling therapy.

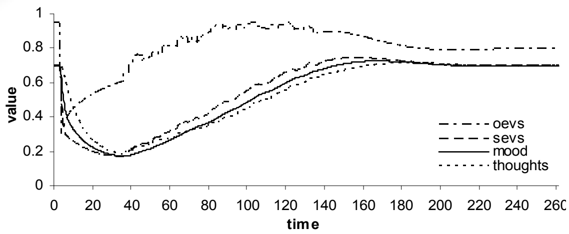

Figure 8: Unhealthy person, 1 negative event, web-based activity scheduling therapy with smartphone.

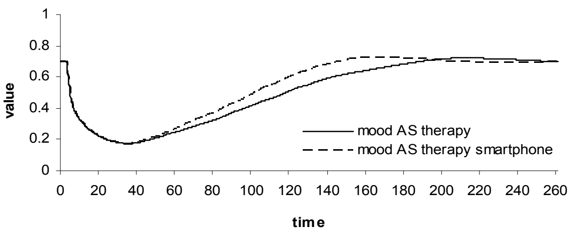

Figure 9: Comparison of mood level between activity scheduling with and without smartphone.

reflection and consequently the coping skills). Figure 9 depicts the mood-level of both types of therapy in one diagram. The additional effect of the supportive system is that the patient recovers more quickly from the depression, and that his coping skills at the end of the simulation are higher.

6 DISCUSSION

In this paper the design of an ambient intelligent system to support people that receive activity scheduling therapy is introduced. The system adds personalized support for patients by analyzing their behavior and giving them reminders, advices and feedback during the therapy. Although the system acts according to static rules, the rules are triggered by actions (or the lack of actions) of patients, and as such it provides personalized actions. The main rules of the system are described and formalized in a simulation environment, thus allowing for automated simulation of the system.

Secondly, based on an earlier model of the dynamics of mood and depression, an extension is presented that explains the effect of (activity scheduling) intervention. This extended model is used to simulate a patient that receives therapy. Together with the simulation of the system, it is shown that the ambient assistive system indeed helps a patient to recover more quickly from a depression, by improving his adherence to the therapy and increasing the level of feedback. Of course, these conclusions are dependant on the assumptions that underlie the model; however, as have been shown in earlier work (Both et.al., 2008), the assumptions are in line with the major psychological literature about depression (therapy). Therefore, it seems reasonable to use the model to evaluate the added value of a specific type of support.

In the first half of 2009, a clinical trial is planned in which this system will be tested in practice. This requires a more detailed development of the interface used in the smartphone to allow for simple reporting of the mood level and performed activities. In the future, we will work on a new version of the system that uses the model of depression and therapy described in this paper to reason about the state of the patient. Using this, it would be possible to give even more personalized advices, based on the predicted effect of the behavior of a patient. This would require a more thorough validation of the model for mood and depression, as the actions of the system will then depend on its correctness. In the current version, there are no ethical deliberations, as all proposed actions towards patients are already validated and tested as part of the existing therapy.

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