Project proposal for MSc Embedded Systems

TU Delft – Interactive Intelligence

User valued smart reminders: Finding Appropriate Moments for Support in Socially Adaptive Electronic Partners

Remy Kabel

4132165

Supervised by:  
Dr. M. Birna van Riemsdijk  
Dr. Myrthe Tielman

30-04-2018

# Synopsis

This project will focus on finding what defines an appropriate moment in regards to providing support through a Social Adaptive Electronic Partner (SAEP). It paves the way to ultimately answering the question “Given a user’s daily activity, what is considered an appropriate time for support feed-back, taking into consideration the user’s norms and values, to achieve a certain goal?”.

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# Project fundamentals

## Introduction

The use of technology to support the daily lives of people is an ever-prevalent topic. Through applications in smart homes, wearables, virtual coaches and many others, we can improve our health, efficiency and be more connected. Conversely, the abundance of apps and notifications causes us to grow immune to the constant stream of information that is presented to us in a daily basis [1]. Especially the elderly or people with a mental impairment could benefit from an effective support agent [2]–[7]. In order to create a truly effective support agent, it is crucial to not only generate feedback in relation to the user’s actions but to provide this feedback at an appropriate time.

But what actually is an appropriate time? The appropriate time for feedback is inherently linked to the nature of the user’s action. To illustrate this, consider the following examples.

1. An elderly lady, Joanna, forgets to call an important client during the day. She wants to be reminded the next day at work.
2. An elderly gentleman, Peter, forgets to take his medicine. Since he has high blood pressure, timely consumption is of importance.

In the first example, a simple reminder notification will suffice. A naïve solution would be to use a simple alarm or reminder app in which she sets a time that is deemed appropriate. However, what happens if the next day, that time is no longer appropriate because, for example, a meeting is planned. Most likely, she will read and immediately ignore the message, forgetting about it once again because at that moment, the meeting is more important to her. Ideally, her phone would analyze her schedule and remind her outside of meetings and before the end the day.

In the second example, prompt notification is of the essence. Not taking the medicine in time severely demotes health; a value which Peter probably values greatly. As such, almost any action should be interrupted for this. However, the intake of medicine is also very predictable. So rather than interrupting any activity, the moment should be preempted and any interruptions should be avoided.

Identifying such an appropriate time for support feedback for a specific scenario is not difficult. The difficulty of this lies in the generalization. While the above examples can be implemented relatively easy at design time, diversions from normal behavior are not handled. Existing technologies are often made by hardwiring norms and as such are very rigid and unable to adapt to evolving norms [8]. Furthermore, dealing with different problems, such as remembering to turn on the alarm system before leaving work, would require a completely different implementation. Nonetheless, generalization requires analysis of goals and the values underlying the user’s daily activities.

## Problem description

The problem of finding boils down to a few steps; each worth further analysis in their own right. For now, an even simpler problem is considered, not forgetting your keys.

Working our way back, the first question that arises is what defines the goal. The goal is defined by the users and can be anything such as: *“I want have my keys with me when I leave home”.* Assuming we know the user’s activities of daily living (ADL), and consequently the location of the keys at any moment, the first step is analyzing which prerequisites there are to attaining that goal. Usually, a goal is not an independent action taken, but rather the consequence of a series of actions. As such, knowledge is required on how a goal be deconstructed into a number of distinct prerequisites.

In order to analyze arriving at this goal, some sort of model needs to be created from the user’s ADL. Once this model has been created, we can use it to analyze the limits of the possible moments for support. More directly, the prerequisites will indicate a number of actions that will have to have been completed, but also some actions may not have been completed. For example, a user will first have to arrive home, but should have received the support feedback before leaving once again, when the user will need their keys. However, Finding the most suitable moment for support is dependent on more than just this.

Finding the most “appropriate” time for the support feedback boils down to finding a moment which is both maximally effective and minimally invasive. For example, sounding an alarm in the middle of a person’s sleep may be very effective, but it sure is annoying. The problem is, however, that it’s difficult to quantify invasiveness.

Summarizing, the required steps are:

* Definition of the goal and its prerequisites
* Analysis and modelling of the user’s ADL
* Analysis of effectivity
* Analysis of invasiveness

## Initial research

The concept of a Socially Adaptive Electronic Partner (SAEP) has been previously introduced by van Riemsdijk [8]. It follows the ideology that technology should adapt to the user and not vice versa. As such, its logic incorporates the norms and values of the social context. Subsequent work has been done expanding on this, including temporal logic and analyzing actions and habits. [9]–[11].

### Existing implementations

More and more apps are taking advantage of the increased use of smart devices and services in order to get a more accurate picture of the user’s ADL. Examples include:

Olisto/IFTTT [12], [13] Can combine date, location and smart device information to, for example, give reminders when leaving home and a specific power consumption is still high (i.e. the TV is still on) and subsequently turn it off.

Maps/Waze [14]–[16] Combines real-time traffic information and address in calendar events to provide timely departure reminders.

Timeful [17] Combines user activity, calendar and to-do items to estimate duration of to-do items, plan them in and generate reminders at off-peak times.

While very promising implementations, most apps predominantly rely on design time logic. Exceptions to this usually create a predictive model and verify this with the user in order to strengthen the model [17], [18].

### Prior research

There have been various approaches as to how and when to provide feedback to the user. Generally, the preferred method of feedback is “smart reminders” [19]. Similar to the implementations, papers frequently focus on finding novel ways of combining information from smart devices into producing reminders, following norms provided at design time. Examples include combinations of location and time [20]–[22], events based on smart devices [3], [23], [24], or a combination of numerous sources of information [25]–[27].

The more innovative ideas add an extra logic layer on top of the data of the user’s ADL. Analyzing the user’s values is an intrinsic part of establishing a model. A simple but tedious approach is to ask for user feedback whenever values are needed. Instead, Zhou et al. [28] use a fuzzy linguistic approach to determine value levels.

Rather than specifying norms at design time, they are constructed based on the ADL. Several approaches are proposed. Chaminda et al. [29] suggest coupling complex activities that have a strong relationship among initiation and conclusion, such as closing the tap after opening it. Other papers [2], [30] support this analysis of temporal relationships between activities, in order to generate a set of norms for the support agent. Other context-aware approaches vary greatly. For example, Vurgun et al. [31] apply a dynamic Bayesian statistical approach. Giorgini et al. [32] use label propagation algorithms to break down goals and identify all prior actions necessary to achieve the goal.

Another approach for this makes use of Behavior Change Support Systems (BCSS) [33] by applying principles of Human Computer Interaction (HCI) [34]. This practice is used increasingly in health focused applications to make sense of the abundance of data. Examples of applications [35], [36] share large similarities with the analysis of the user’s norms and values.

## Research description

As previously mentioned, there are several steps in finding an appropriate time for supportive feedback. However, time is limited and several aspects have already been researched plenty. As such, let us limit the focus of the thesis research.

The first two steps, goal definition and ADL analysis are all linked to activity recognition and analysis to provide smart reminders. As discussed in the previous paragraph, several models covering exactly this already exist. Each having their own properties, advantages and disadvantages.

The effectiveness and invasiveness are both quite difficult to quantify. However, they can be combined into user values. These, in return, are more quantifiable. To illustrate this, let us revisit the example of the elderly man, Peter. The goal, taking his medicine in time, drastically promotes his value of health. The moment the supportive feedback is provided, however, may demote that value or another. For example, if it causes him to wake up from his sleep, it will demote his value of health, or if it interrupts him during a phone call it may demote his value of social contact.

Combining the previous matters and these realizations, the focus of this thesis will be combining the concepts of a SAEP and expanding on the existing research as discussed before. The overall research question is:

How can existing smart reminder systems be extended to incorporate user values to provide appropriately timed supportive feedback and thereby increase the user values.

The expected outcome of this question is a model which provides timed feedback based on the user’s ADL and value input.

Subsequently this leads to a number of sub-questions that need to be answered before this:

R1: What are the requirements for the smart reminder system model?

R2: Which existing models and systems exist for smart reminder systems and how do they compare.

These two questions should provide a good overview on the abilities of the existing systems and the amount of work required to extend them to incorporate user values. Of course, for this we need to be able to actually find out about the user values.

R3: What are possible ways of analyzing and quantifying the values of the user?

R4: How can the model be extended to incorporate user values?

Ultimately, all knowledge can be combined into a model which can be used to approximate the most “appropriate time” for support feedback. This model can subsequently be implemented in a piece of software in order for the model to be dynamically generated depending on new input regarding the ADL, goals, norms and values. Once such an implementation has been made, the model can be tweaked according to findings and should be tested. This brings us to the final sub-question:

R5: Does the use of the extended model improve support for user values?

This will require prior planning of possible testing methods and clearly defined testing scenarios.

# Research

## Existing implementations

**Gate reminder [23]:**

This concept centralizes around providing reminders at the moment a user leaves their house. Knowledge about possibly forgotten items is obtained through the use of RFID tags, focusing on a zero user workload interaction. A crucial part in its working is that it is focused on Korean household, where shoes are generally left at the front door, so there is a clearly defined time slot in which all tags can be analyzed. Focus on the study was mostly the actual prototype rather than any smart algorithm.

*Special properties:*

* Physical prototype
* Transparent interaction
* Object detection

Decision maker [37]:

This concept intercepts notifications from all sources and processes them in a “decision maker” prior to actually arriving at the user. Instead, it processes information from sensors and IoT devices within user and environment contexts to decide upon the target device, type of notification and time of notification. This is done using a machine learning approach. Rather than analyzing the actual patterns in decisions on whether to and how to notify, the paper continues by focusing mostly on the speed and accuracy of various machine learning algorithms.

Special properties:

* Machine learning
* Habit analysis

Smart reminder system [29]:

This concept creates a smart reminder system through three major components: activity recognition, location recognition and prediction. The activity recognition is done through the use of analysis of the hand movements over time and applying machine learning algorithms and fuzzy logic to map this to activities. Location recognition is done through image recognition by camera and neural networks. These two are then combined to analyze coupled activities, two activities that are strongly related. Alongside, predictions are made regarding pending and forgotten activities. As such reminders can be produced when likely to be forgotten activities should occur.

Special properties:

* Specific setup

Olisto/IFTTT/CybreMinder/CAMP [12], [13], [31], [38]:

These apps and concepts allow setting reminders based on various aspects of user and environment contexts. Once the current situation satisfies all conditions in all contexts, the user is automatically notified. Information is retrieved from the user’s (IoT) devices and (online) services. No form of pattern recognition or prediction is done, however.

Special properties:

* Existing (possibly discontinued) apps

CogKnow [25]:

This concept actually touches upon user values, but instead uses them to define the required support. A distinct number of support scenarios are handled and rulesets are defined accordingly. Predominantly the user context is considered rather than anything else. The rulesets are aimed at avoiding interruptions of important activities, but don’t do any further analysis.

Fuzzy linguistics [28]:

This concept uses fuzzy logic and linguistic variables to analyze the urgency of the reminder and the level of annoyance created by the interruption of the current activity. Resulting from this is a reminder level which determines whether or not the reminder is delayed and/or how the reminder is presented. The urgencies and other levels are all given at design time, however, and are averaged over all users tested prior.

Goal models [32]:

This concept does not directly involve itself with reminders, but rather with linking certain activities to achieving certain goals. These activities may have complex relations with one another and may promote or demote a goal. As such, this can be similarly applied to activities aiming to achieve a certain goal where the promotions and demotions are linked to the user values.

Special properties:

* Linking activities to goals
* Not related to reminders

PAIR [2]:

This is a relatively older paper which describes one of the first, more advance planners. It takes into consideration several rules as prescribed by the user or caregiver and lays them alongside the activities of the user to provide appropriate reminders. However, no dynamic analysis is done, only design time rules are analyzed.

AHCS/TAFETA [4], [27]:

These concepts attempt to design a context-aware application which analyses data from various sensors within the user’s house. AHCS makes use of the CASanDRA framework [39] in order to create awareness of the user’s context. The CASanDRA framework is a middleware which provides easily consumable context information and accepts different information inputs which are fused together. The concepts use either the middleware or their own AI to analyze the collected information and compare this with a number of predefined rules to provide detailed information on the user to the caregiver and provide reminders when rules are broken.

Special properties:

* Context analysis independent from reminder system
* Levels and types of alerting

Supporting daily activities [40]:

Why is this PDF not available anywhere…? It seems very interesting: mailed the author.

HeadacheCoach [35]:

While not directly a reminder system, HeadacheCoach does propose a possibly usable system. It uses user and environmental context analysis to identify possible triggers for a headache and consequently provides possible solution. A similar approach may be used to identify moments of lower cognitive ability in order to preempt a reminder being necessary at all.

What should I do/Action Hierarchies [11], [41]:

These two papers, while again not a directly related to reminders, do portray several underlaying concepts. The first paper presents a framework which represents hierarchical relationships among actions. This is formalized in the second paper. Secondly, this framework shows how the relationships tie in with promotion and demotion of values. Lastly, a method is shown on how to infer norms from values rather than vice versa. However, this remains a very theoretical paper.

Special properties:

* Values → Norms
* Not directly related to reminders
* Action hierarchy

CIA [19]:

Although this paper clearly states “smart reminder”, it doesn’t actually do much in regards to reminding. Instead, it uses image recognition to identify people. After this identification it combines information previously gathered through various systems to display information regarding this person and possible events and reminders tied to them.

Special properties:

* Linking information
* Not directly related to reminders

Attelia [1]:

Attelia is a middleware concept which intercepts any notifications. It analyses breakpoints in the user’s mobile interactions and adaptively delivers the notification to minimize interruptions and the user’s attentional overload. As such, it lowers the user’s frustration caused by receiving too many notifications.

Special properties:

* Focuses on mobile screen use to analyze activity

TEREDA [30]:

Another concept not directly related to reminders. It works by gathering simple data from many sensors around the house and feeding that into the middleware. From this, distributions for the start time and duration are analyzed and used to help recognize activities and cluster them by starting time. For example, there might be 4 clusters of starting times in which the user may generally start to watch TV (with corresponding durations). Each of these clusters may have different subsequent activities, each with different likelihoods. As such, this temporal analysis may be used to predict the likely following activity.

Special properties:

* Activity clustering
* Prediction of next activity without machine learning

MLCARS [42]:

This dissertation discusses a concept which uses machine learning to analyze shopping items and where they were bought (or cleared off the to-do list) to predict similar available items or similar stores. This data is collected among all users and combined with information from companies and stores and ultimately stored in a database which is continuously updated. Combining this with the data of the user’s shopping list as well as their location allows to provide appropriately timed reminders not to forget items from their shopping list. These reminders are not just when near their usual supermarket (like is already possible with location-based reminders) but also when close to any store that is expected to have the desired item.

Special properties:

* Activity clustering
* Prediction of next activity without machine learning

MagHive [43]:

This honeycomb shaped magnetic smart surface is attached to the wall and allows devices and other objects to be placed on them. Aside from the useful functionalities such as wireless phone charging, it uses NFC and QI technologies to detect the presence and identity of the objects. As such it is able to remind the user when he or she forgets to take or put back an item.

Special properties:

* Actual product
* Provides a great base for further development

Long term evaluation of smart homes [44]:

Another one not related to reminders per se. This dissertation reviews the users values over long time use of smart home appliances. Their conclusions span generally across all types of smart home appliances. In order for the appliances to provide usefulness it is important that the values of accessibility and trust are upheld. Any appliance which does promote accessibility immediately diminishes any usefulness for the user. Trust generally boils down to the reliability of the provided functionality. If the product still has function impairing bugs, users are likely not to use the product. Even if the producer manages to fix the flaws, the lost trust takes vast time to recover. Another drawn conclusion is that whatever solution implemented, users are initially curious and excited and are willing to try most ideas, but ultimately go back to their routine behavior. As such, the smart appliance should blend into this rather than interrupting it.

### Comparison

Below is a comparison of the previously described implementations. Said implementations are compared at several important factors.

| Concept | RP | RI | SS | Tim | Loc | Act | Env | Dyn | UV | IA | Ref. |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Gate reminder | x |  | x |  |  |  | x |  |  |  | [23] |
| Decision maker |  | x |  | x | x | x | x | x |  |  | [37] |
| SRS | x |  | x |  | x | x |  | x |  |  | [29] |
| Olisto | x |  |  | x | x | x | x |  |  |  | [12] |
| IFTTT | x |  |  | x | x | x | x |  |  |  | [13] |
| CybreMinder | x |  |  | x | x | x |  |  |  |  | [38] |
| CAMP | x |  |  |  |  |  |  |  |  |  | [31] |
| CogKnow | x |  | x | x | x | x |  |  | x\* | x | [25] |
| Fuzzy lingustics |  | x |  |  |  | x |  |  |  | x | [28] |
| Goal models |  |  |  |  |  | x |  | x |  |  | [32] |
| PAIR |  | x |  |  |  | x |  |  |  |  | [2] |
| AHCS | x |  |  | x | x | x | x |  |  |  | [27] |
| TAFETA | x |  |  | x | x | x | x |  |  |  | [4] |
| SDA |  |  |  |  |  |  |  |  |  |  | [40] |
| HeadacheCoach |  |  |  | x | x | x | x |  |  |  | [35] |
| WSID/AH |  |  |  | x | x | x | x | x | x |  | [11], [41] |
| CIA |  |  |  |  |  |  |  |  |  |  | [19] |
| Attelia |  | x |  |  |  |  |  |  |  | x | [1] |
| TEREDA |  |  |  | x |  | x |  | x |  |  | [30] |
| MLCARS | x |  |  |  | x |  |  | x |  |  | [42] |
| MagHive | x |  | x |  |  |  | x | x |  |  | [43] |
| LTE SH |  |  |  |  |  |  |  |  | x |  | [44] |

\* Only at design time

**Legend:**

RP: Reminder Producing

RI: Reminder Intercepting

SS: Specific setup

Tim: Time

Loc: Location

Act: Activity

Env: Environment

Dyn: Dynamic

UV: User Values

IA: Interrupt Analysis

## Discussion

Overall the smart reminder concepts can be divided based on two distinct features. Firstly, those requiring a specific set-up of hardware. And secondly, those that use any sort of dynamic AI over simply hardcoding rules at design time.

The specific set-up concepts are quite apt and able for those scenarios, but quickly fall short when applied to other scenarios or when generalizing the solution.

The majority of the concepts use (or can use) information about the user’s activity to some extent. This activity information can either be used to instigate the notification, or to analyze However, there are a few which take it further and use machine learning or other methods in order to predict the subsequent activity.

Generally, user values are not something linked to timing smart reminders. To less or more extent, however, they are being used at design time to shape the model.

So, what is useful? There is no existing implementation that can immediately be extended with user values. However, there are several implementations that contain interesting ideas that can be combined. Most notably [4], [12], [27], [28], [30], [32], [41].

## Feasibility

If the desire is to combine the concept of the aforementioned papers, just like with any store-bought product, it is important to check whether they actually deliver. Additionally, the question is to what extent these concepts can be used to create a value based smart reminder system.

Firstly, the data collection concepts. Thank to close ties with the company behind Olisto [12], access is granted to all services and code behind. As such, a simple middleware can easily be built and integrated into their existing infrastructure. Using their information provides direct insight into events (such as device alarms) and states of devices (such as door open or closed) and services (such as weather). This is already an up and running platform, so lots of data is readily available.

Aside from gathering and analyzing data ourselves, there are numerous existing data sets. Two of which, are directly provided [45], [46] and probably more are available. These datasets have a range of activities and other data recorded over time. Note that in [37], the first dataset was used, but synthetically enhanced to add several properties such as the user activity other than call information and mobile phone usage. The second dataset has a limited but clear number of activities which are recognized and as such more readily usable. These, and similar, datasets can be used both for design and for testing. The range of activities recorded in these datasets and platforms limits the applicable scenarios. As such the data source should be chosen before the initial designs are done.

Secondly, how to analyze the incoming data. The part of the program analyzing this, or the middleware, is dependent on the type of incoming data. If fully detailed activity information is incoming, the middleware is not necessary since the any further analysis or manipulation can be directly performed on the data. However, when taking information from sensors, such a middleware has to be used to filter any interesting information.

The first solution is writing such a middleware from scratch. This is the most labor intense solution. However, if the other middleware are not easily implementable or require extensive rewrites, starting from scratch may actually require less work. In [4], they did just that; they designed their own middleware. However, it cannot be used since it remains exactly that, a design. In [27], however, they used an existing middleware [39]. In combination with a context toolkit [47], also used in CybreMinder [38]. The CASanDRA framework [39], however shows great promise since it’s actively used. However, up to this moment, 03-08, I have not been able to find the actual implementation. As such I have contacted the authors of the original paper and those of papers which used/referenced it.

Lastly, the most important aspect is the actual analysis. A wonderful starting point from within this research group is that of Tielman [41]. Combining its ideas of action hierarchies and values with that of goal reasoning [32] and possibly that of temporal analysis [30] could lead to very interesting results. The goal reasoning will allow for analyzing the possibilities of the moments of reminding (i.e. before it’s too late). The temporal analysis will allow for better predictions. The authors have been contacted for the actual code behind. However, the description is clear enough to incorporate it without it as well.

**Initial design idea:**

* Do not use any existing middleware
* Use existing datasets as a basis for design
* Construct a middleware for data obtained through Olisto for later testing
* Describe several basic scenarios to test
* Optional: Design basic software code based on [30]
* Design and create basic software based on [32], [41]
* Create analysis of maximizing value (with and without prediction)

# Concept design

The initial design is based on combining the ideas of two papers, [30], [41]. First, a model for activity prediction is made based on existing algorithms such as the Expectation Maximization [48] and Apriori [49], [50] algorithms. Consecutively this model is combined with knowledge of user values to extend the model and allow for statistical analysis in order to predict the most ideal moment for notification.

## Expectation Maximization

Expectation Maximization (EM) is a clustering algorithm which works iteratively to find maximum likelihood parameters of a statistical model. It is used when such parameters cannot be solved through equations directly. The reason for this may be missing data points, latent variables, or further, still unobserved, data points are to be assumed.

Within clustering there is a division between two types: hard and soft (or fuzzy) clustering. In hard clustering, an element either belongs to a cluster or it does not. In soft clustering, on the other hand, elements can belong to multiple clusters but with different degrees of belief, or confidence. In order to statistically analyze soft clustering, mixture models can be used.

Mixture models are a probabilistically sound way of analyzing soft clustering cases. With this method, each cluster is described as a generative model[[1]](#footnote-1), such as a Gaussian or multinomial. However, the parameters of the model are unknown (for example the mean and covariance in the case of a Gaussian model).

If the source cluster of each observation is known, the estimation of these parameters is trivially done through a simple calculation. However, even when not knowing the source, as is the case in a clustering problem, the EM-algorithm will guess the cluster each point likely belongs to. This is done by using the Baysal formulae, those of conditional probability. However, in order to use these formulae, the parameters of the models need to be known. This leads to a “chicken and egg” problem. The algorithm works on any n-dimensional dataset by first performing a random estimate (expectation) to the initial parameters and iteratively improving (maximizing) them.

## Apriori algorithm

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1. In machine learning (and other forms of statistical classification) there are two main approaches: generative and discriminative. Given a target Y and an observation X, the generative model is a statistical model of the joint probability distribution. Whereas the discriminative model looks at conditional probability of Y given X=x. [↑](#footnote-ref-1)