DiasNet Mobile: A Personalized Mobile Diabetes Management and Advisory Service

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Abstract. This paper presents a personalized mobile service for daily management of diabetes. Besides supporting the user in measuring and reporting blood glucose level, insulin intake and physical exercise it facilitates feedback in form of blood glucose simulations from the DIAS (Diabetes Advisory System) decision support system. The service presented in this paper is the final results of an iterative prototyping and evaluation process with potential end-users. Results from the evaluation of the service will be presented and discussed.

1 Introduction

Currently, the monitoring and treatment of diabetics is covering about 6% of the Danish health budget (approximately 335 million Euros) [6]. In this regard Denmark is representative for other Western countries. By year 2000, the number of diabetes incidents worldwide was estimated to be at least 171 million (forecast to be 366 million by 2030); and 33.33 million in Europe alone (forecast to be 47.97 million by 2030) [13]. That is, the DiasNet Mobile service is not a speculative prototype invented for technological reasons alone - it targets a highly relevant area for introducing personalized eHealth services. By making an easy to use service for the daily management of diabetes many of the diabetic complications may be averted, which could mean saving the society for millions of Euros and significantly improving the lives of the users.

The aims of this paper are threefold:

– To show how an existing decision support system for diabetes management and advisory can be integrated into a mobile and personal service for everyday use.
– To present the system and the underlying architecture both from a technical and a user’s perspective.
– To present results from the evaluation process.

1.1 DiasNet

To understand the DiasNet Mobile service it is important to understand it’s foundation. The ideas and the underlying functionalities for the mobile diabetes management service are derived from the DiasNet research project conducted by The Medical Informatics Group at the Department of Health Science and Technology, Aalborg University [1].

DiasNet is a Danish web-based service for type-1 diabetics. Basically the user can access the system from his/her PC through a web interface and enter BG (blood glucose) measurements and other data. The DIAS (Diabetes Advisory System) decision support system is based on a CPN (Causal Probabilistic Network) that models the carbohydrate metabolism of the user. The system can predict the development of the user’s blood glucose measurements by a simulation based on when and what he/she eats and when, how much and what type of insulin is injected. Ideally, the model should also take into consideration the physical activity of the users, so the system also takes exercise information as input. However, this is currently not used in the forecast. The output, as can be seen in figure 1 (from [2]), is a graph showing the actual measurements and the simulated BG concentration. Optimally,
the concentration should be within a defined threshold. If the level gets too low, the user will get very uncomfortable as he/she enters hypoglycemia and if it becomes too high, the user enters hyperglycemia, which is the primary cause for almost all the long-term diabetic complications.

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The original DiasNet service has been running in two pilot projects and has been used by a group of patients in Denmark and in the United Kingdom. The experiences from DiasNet (see [2], [4] and [5]) forms the basis for the further development of the mobile service presented in this paper.

### 1.2 MAGNET

DiasNet Mobile has been developed during the MAGNET (My personal Adaptive Global NET) project and it’s continuation project MAGNET Beyond [3]. MAGNET is focused on introducing novel technologies for personal networking with a profound emphasis on the user. Personalization is a key element in this vision. The focus on eHealth and diabetes is situated in one of two major application areas of the project, named MAGNET.Care. The aim is to show how the integration of MAGNET technologies in the healthcare domain, i.e the realization of personal networks, can improve people’s quality of life.

User-centrality is another key element in the project and through the whole development process a UCD (User-centered design) approach has been taken by directly involving diabetics, medical doctors and nurses in the process.

### 1.3 Paper outline

First the developed system is discussed in section 2 both with regard to the envisioned system and the implemented prototype. Then section 3 discusses the evaluation strategy and methods with emphasis on how end-user involvement has been central for the whole process. The results from the evaluation is presented in section 4 and further discussed in 5. Finally a status of the study and conclusions are presented.

### 2 The system

This section describes the system from different points of view. First the underlying decision support system is discussed, to give a clear idea of the underlying concepts. Then
the envisioned full scale system is presented followed by a description of the implemented prototype. The prototype is presented both from a technical point of view, i.e. the devices and underlying architecture, and from the user’s perspective, i.e. the functionality and how it is used.

2.1 The decision support system

The backend of the DiasNet Mobile service is the DIAS server which runs the CPN model of the user’s carbohydrate metabolism. The CPN has been created and trained on the basis of real patient data and all simulations are done based on a generic model. The model is updated based on the user’s personal measurements, and the simulation results can thus be considered as personalized feedback to his/her diabetes management.

In order to perform a simulation of the blood glucose level DiasNet needs three types of measurements: insulin, carbohydrate intake and previous BG measurements. These data are among others the ones which medical doctors use when they give advice about diabetes treatment and management. Although the carbohydrate metabolism is a complex mechanism and a lot of other factors influence how the individual patients react, e.g. endocrine diseases, pregnancy, stress, alcohol etc., the DIAS system has proven to give quite good predictions based the three abovementioned parameters [4].

In order to obtain a proper simulation result, three days of data must be present before the two days of data, which are of interest when simulating. So to perform a simulation for two days, five days of coherent data are needed. If none of the three types of measurements are present in any of the five days, no simulation should be performed, as this might result in a poor simulation.

Although this service seemingly replaces the doctors role as an advisor, it should more be viewed as a tool for communicating medical data and advice between the doctor and patients. It should be noted that the decision support system is an approximation, and it is by no means perfect. Thus it is very important that the user is always critical about the results. For this reason this system has not been designed to give direct advice e.g. like ”take so and so much insulin”.

An important benefit of reporting the measurements electronically is that the doctor can quickly get an overview of the patients status. The regulation of the treatment can thus be done more efficiently. This can also enhance the communication between the patient and the diabetes clinic, as the competent patient can be allowed to be more autonomous in the management and the focus can be put on those patients that need more directions from the health professionals.

From a learning perspective, the simulations also serves as a tool for visualizing the causality of the carbohydrate metabolism. Thus they can learn about the basics of their carbohydrate metabolism, as they can see the simulated results of e.g. eating a specific amount of food or taken a specific dose of insulin at a given time. The simulations will show if the user’s BG levels has been out of the threshold, and as the main goal of diabetes management is to keep the level within these bounds, the user can use this feedback to regulate his routines. The resulting graph could be motivating factor for the diabetics, as it can be seen if it looks ”nice and within bounds”.

From the above it is easily seen that the existing DiasNet have many positive prospects, so the challenge is to make it as easy to use and available to the diabetics for them to actually use it in their everyday life. This is the rationale for DiasNet Mobile.

2.2 The envisioned system

Although DiasNet Mobile is rooted in health informatics it was brought into the MAGNET.Care case as an example of how personal networks can be used in the healthcare domain. As such it was chosen as a proof-of-concept application of the advanced network technologies which are to be developed through the MAGNET project. In the MAGNET project DiasNet Mobile was called DiasNet-PN (Personally Networked) reflecting the emphasis on Personal Networks. [7] presents the service in this context and [8] documents its
evaluation in a MAGNET perspective. However, since the focus of this paper is not on personal networks and advanced networking concepts, the following discussion of the system will not include these aspects. Instead, the system is presented as a more simple mobile system using existing wireless technologies like GRPS and Bluetooth, which is in fact also the case for the current fully functional prototype.

Figure 3 illustrates the overall system architecture and users. The diabetic user can interact with the system both through the original DiasNet web application and through DiasNet Mobile. The collected data is submitted to the DiasNet server, where it is stored and used for the DIAS simulations. The health care professionals could be doctors and nurses at the diabetic clinic or any other medical staff associated with the treatment of the diabetic. They have access to the user’s data from the DiasNet web interface as well, and can remotely monitor the progress and management of the disease. The dotted line in figure 3 encapsulates the DiasNet Mobile part which has been implemented and tested with the current prototype. Other people might also be interested in monitoring the user’s progress e.g. family, friends and/or caretakers for elderly or disabled. They could also interface to the system through either their PCs or mobile devices. This aspect is very important in the MAGNET project.

2.3 The implemented prototype

The current DiasNet Mobile devices are a Bluetooth enabled blood glucose meter and a Nokia 7710 mobile phone as shown in figure 2. The measurements can be reported directly on the mobile phone or through the blood glucose meter which is used to wirelessly transmit data to the phone. When the user enters a measurement it is done through the GUI. When the mobile phone has received a measurement either directly from the user or the blood glucose meter, it is uploaded to the server via a GPRS connection.

2.4 From the user’s perspective

The following gives a walkthrough of the client application on the phone, which is the main user interface for the service. Figure 4 serves as a reference as it shows the most important screens through which the user will interact with the system. Each screen has been labeled with a letter by which it will be referred in the following description. As the figure illustrates, the functionality can be broken down into the main menu and three categories: input of data, viewing data and other functions.

As can be seen the DiasNet Mobile has a main menu which is the opening screen (A) of the program. Selecting any of the menu items will take the user to the respective subscreens. The tree-like structure of the GUI is a simple way to divide the functionality. By keeping the depth of the tree to a minimum makes the program simple and easy for the users to grasp DiasNet Mobile in its entirety. The input screens, i.e. Blood glucose (B), Carbohydrate (C),
Insulin (D), Exercise (E) and Comments, do not add extra depth in terms of additional subscreens, however the Graph (H) and Table (F) viewing screens does (as can be seen in figure 4).

All the input screens are quite simple and allows the user to input one category of information to the service and submit this. The only input screen which is not shown in figure 4 is the Comment screen, which allows the user to add a comment to his dataset (e.g. "late measurement due to busy morning" or "high BG level, celebrated juniors birthday, had cake").

In the Graph screen (H) it is possible to switch between two viewing modes; one showing insulin and blood glucose levels (I) and another showing the carbohydrate intake (J). Each of these show a timeline consisting of the previous and current day, allowing the user an easy overview of the latest measurements. A colored band is shown in the insulin and blood glucose graph screen indicating safe blood glucose levels. Likewise, in the same screen is a trend curve showing the simulation of the blood glucose level which is similar to the one found in the original web based DiasNet application.

The Table screen (F) allows the user to get a table view (E) containing time stamped events of the blood glucose measurements, insulin and carbohydrate intakes, etc. Basically, it provides the same information as the Graph presented in a different way. It is also possible to switch directly from Graph to Table viewing of the same time period (not shown in figure).

The other functionality (G) (which is not detailed in figure 4 includes settings and a message system. The Message screen shows the incoming messages from the medical team associated with each diabetic. It works in the same way as a traditional email client by showing the content of the inbox with sender and date of message. The Settings screen allow to the user to configure the service and to input relevant data like e.g. which type of long and short-acting insulin should be used as default.

When using the BG meter to take measurements as shown in figure ?? the confirmation on the phone can be disabled in the settings, so that the user does not have to use two devices, but rather the measurements are sent directly to the server. From a user’s perspective the confirmation might make the system feel more secure, so that wrong measurements are not submitted by error, but on the other hand it might be more convenient with no confirmations, as this allows for direct data submissions with no need for using the phone.

**Fig. 3.** The envisioned system
Fig. 4. An overview of the main DiasNet Mobile functionality and GUI. See section 2.4 for further description.
3 Evaluation

The evaluation of the prototype system is an iterative process parallel to that of designing and implementing the prototype system. Every step in this process produces new knowledge about the usability of the system, which is fed back to the development process and helps iterate both the design and implementation [10]. In the spirit of UCD, the potential end-users has been involved through-out this period.

An evaluation strategy was chosen based on principles from interaction design [11] and usability testing [12] practices, and a series of activities has been conducted to produce quantitative as well as qualitative data for evaluation of the service prototype:

**User workshop:** An end-user workshop with the research team, five diabetics, two nurses and a medical doctor was carried out to give initial input to the functionality and design of the service. From this a conceptual model and design was made and a low fidelity prototype was created.

**Expert evaluation:** The first functional prototype of DiasNet Mobile was subjected to an expert evaluation in the form of a heuristic evaluation [9] to ensure compliance with general usability.

**Lab usability test:** The service has been tested through a standard think-aloud usability test in a lab setting to ensure that no critical usability errors persisted. Seven users without prior knowledge of DiasNet and diabetes management was used to verify that even new users would find it intuitive and easy to use. The users went through characteristic scenarios with input of data, viewing data and changing the settings of the service.

**Field trial:** In the final experiment the prototype is to be tested in the natural context by real diabetics over a long period of time. This is the most significant evaluation, as it will reveal whether the potential users of the service find it useful and usable. The field trial is further discussed in the following.

3.1 The field trial

The field trial has been designed as a longitudinal experiment, in order to measure the actual day-to-day utilization of DiasNet Mobile over a prolonged period of time. The ultimate goal is to measure the impact on the everyday life of diabetic patients. Especially to see if the “anytime-anywhere” paradigm will change the usage patterns of the diabetics over time and help them better manage their disease. The usage patterns can then be compared to their existing patterns from the original DiasNet service.

We are interested in looking at the usage both on the large scale (which functionalities are used, when and how often etc.) and at the lower level of the interaction scale (e.g. which buttons are pressed, how long does it take to input a BG measurement, etc.). This is to ensure that the service is indeed both useful and usable.

In the field trial an elaborate data logging scheme is implemented to obtain these data. It is done in the background and is completely transparent to the user (although they are informed about this before the experiments). Also, no personal or other sensitive data is logged. The following are representative examples of usage data which will be logged during the field trial:

- When the service is started and stopped
- Time spend doing each activity e.g. reporting an insulin injection
- Any changes in settings
- Erroneous data entries, exceptions any unexpected system behavior
- Use of the BG-meter

The field trial has been divided into a pilot phase and a main phase. The pilot phase was run as a three month experiment with one user. Currently only the pilot phase has been conducted, and the experiences from the pilot study will be used to refine both the service and the main field experiment before the larger scale main phase is initiated with 7-10 users.

The user selected for the pilot phase had the following characteristics:
– Middle aged male.
– Diagnosed type 1 diabetic and 13 years experience with disease management.
– Proficient computer user and had knowledge of mobile phones and wireless devices.
– Familiar with the original DiasNet service.

The participant was chosen for the pilot phase because of his computer literacy and the fact that he is accustomed with mobile technology and DiasNet. The pilot phase could then be started at an earlier point in development, as he would be able to tolerate more technical errors in the prototype than a person with less experience.

4 Results

The section presents some central findings from the various phases of evaluating the service. They are all explicitly or implicitly related to whether or not the developed service is useful and the usable and/or what aspects should be considered to ensure this from the user’s point of view.

It should be noted that only a few preliminary results from the field trial are presented. This is partly because the data analysis from the pilot study is not yet complete and partly because that study was only conducted with a single user; thus it would not be enough to conclude about the service from this.

4.1 User workshop

The needs and wishes of diabetic patients and health care professionals were explored and user groups were defined based on age and ability: children, teenagers, adults and elderly. Each group has special needs and preferences with regard to functionality and way of interacting with the device. E.g. services for kids and elderly should support remote monitoring by other persons like parents or care takers, as others will often be responsible for managing the disease. Teenagers and adults are more concerned with self-control of their disease and independency which should be reflected in the service being less intrusive.

The most desired functionality from the health care professionals point of view was to take and report insulin and blood glucose measurements in an easy, safe and quick way. Managing the disease can be done more efficiently if more data is available. Normal practice when using the DiasNet service was to note down measurements on paper and manually enter them into the system at some later time (if ever). Many diabetics use their blood glucose measurements for regulating their insulin intake on a daily basis, and do not consider these measurements as part of the long term management of their disease.

The healthcare experts and users do not necessarily share the same view of what a "good" service is. Patients do not want to be too influenced by the service i.e. feel that they are encumbered or controlled by the use of the service.

All patients wanted to carry as few devices as possible, preferably having the service incorporated into the devices they already use.

4.2 Usability testing in the lab and field

The usability of the service has been verified through both the heuristic evaluation and the lab test. The participants found that the service was intuitive, easy to use and the functionality clearly laid-out in the menu structure. Even though several minor usability issues where found (and corrected) the overall evaluation was positive. This view was shared by the pilot test user in the field trial.

The pilot user also found the mobility aspect very convenient since he used it for three months. Being familiar with the original system, he appreciated that he did not have to boot up his PC to enter a single measurement. From the data log it can also be seen that he has been using the service through the whole day including numerous times while he was on work. This finding indicates that the mobile and ubiquitous potential of the service might give rise to new use patterns. Simply because it is easy and quick to report data anytime, anywhere.
5 Discussion

If one is to consider the significance of the evaluation results, care should be taken before concluding about the service. Especially, there are a number of uncertainties associated with the field trial and looking at data logs. Of course the experiment, even though placed in a natural setting, is an artificial situation, and the user behavior might be influenced by the fact that he/she is part of an experiment. The philosophy is that doing a longitudinal study will negate this effect. Logged data can also be tricky, since it can be difficult to see what the user’s actual intention was.

While the usability has been verified through several experiments, the claim of usefulness is much more elusive. Empirical data from a longitudinal field trial with ten users will definitely make a stronger case than the pilot phase of this study. Since it has only been conducted with one user.

To argue for the usefulness of the service, the following instead summarize the most important ways in which the user can benefit from the system. These are key points which are equally valid for both the original DiasNet and DiasNet Mobile:

- Learning about diabetes and how their carbohydrate metabolism works.
- Easy way of keeping status both for the user and the healthcare professionals, and it creates a communication link between the healthcare professionals and the user.
- Better and more up-to-date data means better management of disease which ultimately means better health for the patients and savings on the public healthcare budget.
- User can be motivated by the fact that their disease management efforts are visualized both for themselves and the healthcare experts.

Besides inheriting all these from the existing service, DiasNet Mobile further adds the following benefits which should make it even more desirable for diabetics to use the service:

- It has an easy to use, simple and intuitive interface on a mobile device.
- It enables a high degree of mobility so that it can be used (almost) anytime and anywhere.
- It brings a personalized eHealth service to the users personal device.
- The user does not need to wear additional devices.

The personalization of the service could further enhanced by applying user modeling. E.g. by modeling when and how the user reports data the system interface could be adapted to emphasize functionality for supporting the most probable task of the user. Also the input range and default values when reporting data could be fit to the users profile. If the usage patterns are regular, the user model may also be used for reminding the user of a potentially forgotten report (e.g. if no carbohydrates are reported at lunch time).

5.1 Conclusions

The presented service prototype and its evaluation is an example of how future eHealth services for management of diabetes or other chronic diseases can be realized. It can be seen as a proof-of-concept that a relatively advanced eHealth service like DiasNet can be realized as a service on a small mobile device.

User centricity has been a corner stone in the development of the prototype system, and it could be argued, that the final version is an iteratively refined and improved version of the ideas which the potential users themselves has put into it from the beginning.

From the evaluation of DiasNet Mobile it can be concluded that the usability of the current prototype has been verified and that users had a positive attitude towards it. However, there is currently no experimental evidence of significance for the usefulness of the system. Further study of the service in the field will prove whether DiasNet Mobile is both useful and usable enough that diabetic patients are willing to use it on a regular basis, and even further studies must be conducted to see if it will have a significant impact on disease management.
5.2 Further work

The main phase of the field trial is in the making. Based on the experiences from the pilot phase, it is expected that the field trial will generate a large amount of usage data from which further conclusions can be drawn about the service. Hopefully this will ultimately lead to knowledge about how mobile and personal eHealth services can have an impact on peoples lives.

Also the development of the diabetes service in the MAGNET.Care case is being further expanded to a more general "lifestyle companion" incorporating general health, exercise and diet related information.

6 Acknowledgments

The work presented in this paper is part of MAGNET Beyond which is a continuation of the MAGNET project (www.ist-magnet.org). MAGNET Beyond is a worldwide R&D project within Mobile and Wireless Systems and Platforms Beyond 3G. MAGNET Beyond will introduce new technologies, systems, and applications that are at the same time user-centric and secure. MAGNET Beyond will develop user-centric business model concepts for secure Personal Networks in multi-network, multi-device, and multi-user environments. MAGNET Beyond has 32 partners from 15 countries, among these highly influential Industrial Partners, Universities, Research Centres, and SMEs.

References

1. URL: http://www.mi.hst.aau.dk.
2. URL: http://www.mi.hst.aau.dk/~spp/.
8. MAGNET deliverable 1.2.2. Report on field trial results, 2005.