D1NAMO, A Personal Health System for Glycemic Events Detection

Fabien Dubosson[1] and **Stefano Bromuri**[2] and **Jean-Eudes Ranvier**[3] and **Michael Schumacher**[4]

Abstract. Several approaches are used nowadays to help diabetic people to handle their disease, one of them being the self-management of diabetes. We developed in this context a platform allowing patients to report and log their symptoms, medications and glucose levels through an Android application. In addition to self-management, the *D1NAMO* project aims at using ECG signals in order to detect glycemic events and eventually predict glycemia levels. The BioHarness Zephyr 3 sensor has been integrated in the platform for this purpose. The resulting platform is a full-stack personal health system for diabetes self-management with support for physiological signals such as ECG: a physiological signals sensor, an Android application, a central server, a database and a few webpages are composing it. The question of the data lifecycle management in regards to the platform usages is discussed.

1 INTRODUCTION

The diabetes (diabetes mellitus) is a metabolic disorder characterized by chronic hyperglycemias — excessive glucose in the blood — due to defects in insulin level [1]. The type 1 diabetes includes causes due to a failure in the creation of the cells producing the insulin. The only treatment consists of taking insulin shots several times a day in order to regulate blood glucose level.

Several problems can arise from long-term diabetes, such as excessive risks of vascular diseases [2] or even damage, dysfunction and failure of various organs such as eyes and kidneys [1, 3]. Intensively controlled glycemia get type 1 patients to have a higher outcome on the risk of developing cardiovascular disease [3].

Insulin injections should be dosed correctly to avoid hypoglycemias — insufficient glucose in the blood — which are common side-effect of insulin therapy, especially for type 1 diabetes [6]. Severe hypoglycemias could be harmful for patients. This means there exists a trade-off between limiting the frequency of hypoglycemia while preventing cardiovascular disease later in patient's life.

The management of diabetes requires to take a drop of blood several times a day in order to measure the patient's glucose level. This measurement method is intrusive and the *D1NAMO* project aims at exploring an alternative method using a non-intrusive measurement method that requires the collection of Electrocardiogram (ECG) data from patients in order to process them with machine learning algorithms. Such system would improve the quality of life of patients in two different ways. First by avoiding the patients to have to use intrusive measurement methods, and second by removing the need of patients to think about checking regularly for hyper/hypo-glycemia, delegating this to an application that will throw alerts in such cases.

Up to our knowledge, no platform nor experiment to use the BioHarness' ECG in order to detect hypo/hyper-glycemia has been made yet. A review paper [4] explores the use of sensors to improve management of glucose and references two articles [10, 11] that are presenting methods that use the BioHarness, but only on Accelerometers and Heart Rate signals.

The presentation of the *D1NAMO* project is made in the next section and the developed platform is described in the following one. A last section discuss the data lifecycle in regard to the platform usages.

2 D1NAMO

The *D1NAMO* acronym stands for *Diabetes type 1 Non-invasive Activity MOnitoring* and aims at providing to type 1 diabetic patients a non-invasive way to manage their chronic disease. Several studies have shown that hypoglycemias are causing some modifications in the PQRST characteristics of ECGs, especially a prolongation in the QT intervals [5, 7, 8], as presented in Figure 1. One of these studies also suggests that this may allow the development of an hypoglycemia detection device [8]. The *D1NAMO* project aims at using such technology to monitor type 1 diabetes in a non-invasive way.

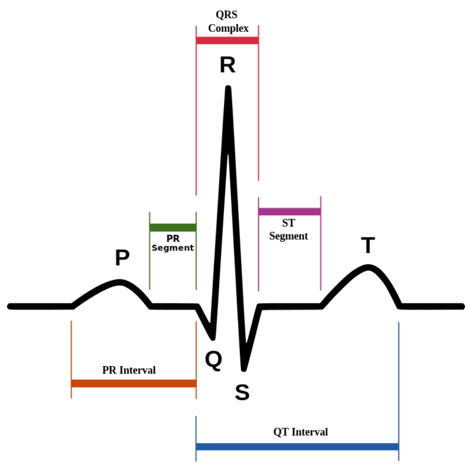

Figure 1. The PQRST characteristics with the QT interval

The *D1NAMO* concept is the following: Diabetic patients are wearing an ECG sensor which is connected by Bluetooth to their smartphones. An Android application acts there as a controller to

[1] HES-SO Valais//Wallis, Switzerland, fabien.dubosson@hevs.ch
[2] Open University of the Netherlands, stefano.bromuri@ou.nl
[3] EPFL, Switzerland, jean-eudes.ranvier@epfl.ch
[4] HES-SO Valais//Wallis, Switzerland, michael.schumacher@hevs.ch

start/stop data transmission, as an helper to manage the disease by offering an interface to manually keep track of events, and as a buffer to store data while dealing with connectivity issues. The application send the data to a server that will analyze them on arrival, and then store them in a database for visualization. In case of a detected event, an alert is sent to the patient's phone, warning him about a potential event and asking him to take further measurements. Finally a web interface allows medical doctors to see their patients' data.

The studies having shown the prolongation of the QT interval have been made in a clinical setup by using medical-grade ECG devices. The *D1NAMO* project does not fit in such category as it is based on a commercial sport-like chest belt for acquiring ECGs: The Zephyr BioHarness 3 shown in Figure 2. The feasibility of hypolgycemias detection in a real-life setup with a non-medical device is the goal of another part of the *D1NAMO* project: some preliminary results with models description are presented in [9].

Figure 2. The Zephyr BioHarness sensor with its belt

The usual management of type 1 diabetes only requires patients to have a small pocket with them containing some needles, a stylus for needles, and a glucometer. The requirements for getting ECG data, as needed by the *D1NAMO* project, are quite different: an ECG sensor and a smartphone. Additionally, the treatment of acquired ECG data requires a network connection on the phone in order to send the signals to a server, which will apply machine learning processing. Data are stored in a database by the server, and finally a web interface is needed to consult the data. The following section describes in more details all these components.

3 PLATFORM

The overall *D1NAMO* platform is depicted in the Figure 3. This section describes in more details each component individually.

3.1 Sensor

The device that has been selected for *D1NAMO* is the Zephyr BioHarness 3[5]. The selection has been made by a ponderation of different criterias such as price, ECG capabilities or connectivity. It is a sport-like chest-belt — shown in Figure 2 — that allows the acquisition of different kind of signals. It has three main sensors: ECG, Breathing, and Accelerometers; from which it is also able to extract higher level information. The data available over bluetooth are:

- ECG signal (250 Hz)
- Breathing signal (18 Hz)

[5] http://www.zephyranywhere.com/products/bioharness-3

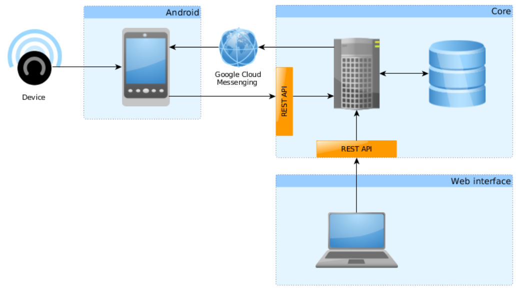

Figure 3. The overall platform architecture

- 3D Accelerometers signal (50 Hz)
- General information (1 Hz), among which:
  - Heart rate
  - Breathing rate
  - Posture
  - Activity level
  - Statistics like amplitude, noise, peaks, max or min about base signals

The device can be configured — over bluetooth — to send only the requested kinds of signals, meaning it is possible to optimize the battery life by requesting only the needed information.

3.2 Android

The sensor is connected by bluetooth to an Android application (Figure 4). The application asks the user to enable the bluetooth if not already done and offers a configuration menu to select the Bluetooth device to use. Another menu allows patients to select which packets should be sent from the device.

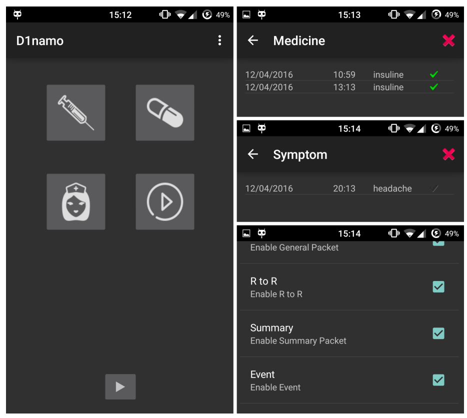

Figure 4. Some screens of the Android application

As the smartphone connectivity may be interrupted, the Android application has been designed to serve as a data buffer. This means that the data are not continuously sent over the network, but that the application gather the data locally before sending them as a batch on a regular time interval, or when a given memory threshold has been reached. Another benefit of this approach is the battery saving that arise of not having the data channel open all the time.

The application also provides helping functionalities for diabetes management. Patients are offered interfaces for manually entering glucose measurement, medications and symptoms they may have taken/noticed. This can be seen as a personal diary allowing patients to discuss with the medical staff if the later notice anormal patterns in their signals.

3.3 Server

A central server gather the data from the Android application in order to process them by applying machine learning algorithms. The algorithms – worked out on another part of the *D1NAMO* project [9] – will be integrated once performances would have been evaluated. The server is responsible to save the data inside a database in order to allow later visualization of the signals by the medical staff. For keeping the access to the data centralized, only the server is accessing the database but it provides an API to query the data.

The server application has been developed with Spring and JavaEE technologies on top of the Wildfly[6] application server. Communication with the server are done through two different APIs, one allowing to receive data from the android application, and another one allowing to query data from the database. The communication through receiving API is not yet protected, but a placeholder library for encryption is already present in the pipeline. The decision on the encryption technology and algorithms still remains to be done.

3.4 Database

A PostgreSQL[7] database is used to store the users physiological signals on the server side. A standard database table is used for storing users credentials, with a hashed and salted format for the password fields. The storage of data from the sensor is not done by saving one data per row as it is usually done, but instead by saving the data as gathered from the device in a bytes array format: the Zephyr sensor is using all bits of the packets sent over Bluetooth in order to minimize the energy needed. Saving the data in this format requires some processing for accessing data later on, so this may be changed in the future.

More generally, some discussions about the usefulness to keep all the records should be made with the medical staff. It should be possible to use some heuristics to discard records older than a given threshold age or to remove already seen data, with a feature to lock and prevent interesting ones to be removed.

3.5 Web interface

The platform currently comes with a few simple web pages allowing to manage the users (add, edit, delete) and to visualize users' data. The Figure 5 shows what the menu looks like.

All the features of the interfaces have not been implemented yet, but an evaluation of the usability of the existing web pages is planned. It will take the form of an qualitative evaluation with the medical staff and will lead the future development and enhancement of interfaces.

[6] http://wildfly.org/
[7] http://www.postgresql.org/

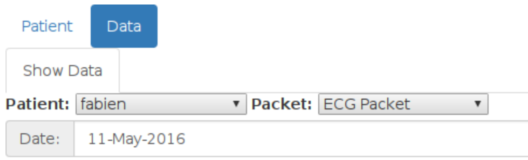

Figure 5. The menu of the web interface

3.6 Deployment

In order to allow an easy deployment of the different components, the docker[8] software has been used. It allows to package binaries of applications with their files in a single entity called a "container". Such container can be build in a reproducible and automated way, and it is possible to reuse existing containers of already packaged software. The PostegreSQL database for instance can be started from an official docker's container, with a single command that will take care of fetching the container online and starting it. The server itself is provided as a docker container. Finally a "Makefile" [9] orchestrates the lunch of the different containers to allow administrators to easily setup the whole platform.

4 DISCUSSION ON DATA LIFECYCLE MANAGEMENT

Signals such as ECG or Accelerometers output are acquired at high-frenquency rates. The BioHarness 3 is getting the ECG signal at 250 Hz, while the Accelerometers are sampled at 3×50Hz and the Breathing at 18 Hz. Storing such kinds of data in relational database tables will grow the number of entries quickly: summing these signals together, they represent 418 values per second, which adds up to more than 1,5 millions entries per hour. The data Acquisition that has been made for the project showed an usage of the device for at least 12h per day. Hence, an instance gathering the data of 20 patients, 12 hours a day during 1 month will accumulate more than 10 billions entries. It is possible to estimate the lower bound of space needed by the generated data. By using the device data sheet, we can get the precision of each kind of signals values, i.e. the number of bits that are used for each:

- ECG: 250 Hz × 10 bits = 2500 bits/second
- Breathing: 18 Hz × 10 bits = 180 bits/second
- Accelerometers: 50 Hz × 3 signals × 10 bits = 1500 bits/second

Which leads to a total of 4180 bits per second, which is around 523 bytes. Using the same scenario as previously described, this sums up to more than 13 GB per month for 20 patients. While good relational databases can handle such high number of queries, and hard drives being cheap enough to handle the storage easily, this is not without raising up some questions about the data lifecycle management.

The different usages of the platform are triggering different needs in term of lifecycle management. Three classes of usages can be derived from the platform: the alerting need for patients, the querying and visualizing needs for the medical staff, and finally the machine learning need for researchers.

[8] http://www.docker.com/
[9] https://www.gnu.org/software/make/

The *patients* need is allowing patients to receive alerts regarding their blood glycemic state. This goal requires the last minutes of received data to be analyzed in order to detect glycemic events. The smartphone is sending data in a batch on regular intervals, so the analyze may be triggered on data reception before putting them into the database.

The *medical staff* needs are the visualization of patients data and the querying of past signals events. Both of these goals are in the target of relational databases as they are made for querying data, either it is for a visualization purpose of for finding event. This brings a first question about the data lifecycle: which data should be kept, for how long, and for which goal. However these questions are easy to address by discussing with the medical staff who can decide which kind of data they want to have, and for how long.

The *researchers* needs are to keep the data available for further research, and using incoming data for training algorithms. Creating backups of all signals for later use in research can be made easily by dumping the database. On the other side, depending on the machine learning techniques used, models refinements are possible. These could be done when data are arriving.

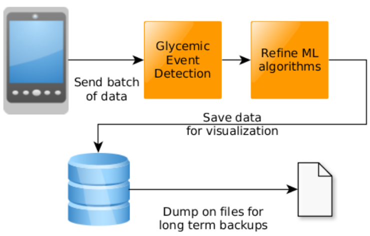

Figure 6. The data lifecycle

The data lifecycle management of such Personal Health Systems could then follow this schema (depicted in Figure 6): The data are sent as batch to the server. Data arrival trigger an analysis of the data in order to detect eventual glycemic events for the patient. The data can then be used to refine machine learning algorithms before being saved in the database. Database dumps could be done when data are needed, or when limits are reached. On a regular basis — that should be discussed with the medical staff — a cleanup of old data can be made to save space and avoid performance issue later on.

5 CONCLUSION AND FUTURE WORK

In this paper we present the platform we developed in the context of the *D1NAMO* project. The platform allows diabetic patients to gather their physiological signals, such as ECG, Breathing or Accelerometers output, into a central database. Predictions about their glycemic states and detection of eventual glycemic events, such as hypo- or hyper-glycemias, can then be made out by using machine learning algorithms. The data lifecycle is also discussed in regards to the different usages of the platform.

By using the platform, medical doctors will be able to access and visualize their patients data. The developed user interfaces are in their first version, but a qualitative evaluation by a medical staff is planned in order to improve their usability. The detection of glycemic events is part of another side of the *D1NAMO* project with some preliminary results, but formal performances evaluation still remains to be done.

Once the *D1NAMO* project will be fully integrated, this platform will serve as a proof of concept for the validation of the feasibility of such non-invasive technologies in real conditions. This platform is not ready for production as several improvements should be made before being used outside of the research area, especially as medical platforms require a special care on security for users and data protection.

The future work on this platform includes the integration of the machine learning algorithms developed on the second part of the *D1NAMO* project, as well as the integration of a query interface to allow the medical staff to search for patterns in the patients data.

ACKNOWLEDGEMENTS

This research has been financed by the *Nano-Tera.ch* initiative through the *D1NAMO* project.

REFERENCES

[1] Kurt George Matthew Mayer Alberti and PZ ft Zimmet, 'Definition, diagnosis and classification of diabetes mellitus and its complications. part 1: diagnosis and classification of diabetes mellitus. provisional report of a who consultation', *Diabetic medicine*, **15**(7), 539–553, (1998).

[2] Emerging Risk Factors Collaboration et al., 'Diabetes mellitus, fasting blood glucose concentration, and risk of vascular disease: a collaborative meta-analysis of 102 prospective studies', *The Lancet*, **375**(9733), 2215–2222, (2010).

[3] Diabetes Control, Complications Trial, et al., 'Intensive diabetes treatment and cardiovascular disease in patients with type 1 diabetes', *The New England journal of medicine*, **353**(25), 2643, (2005).

[4] Sandrine Ding and Michael Schumacher, 'Sensor monitoring of physical activity to improve glucose management in diabetic patients: A review', *Sensors*, **16**(4), 589, (2016).

[5] Bodil Eckert and Carl-David Agardh, 'Hypoglycaemia leads to an increased qt interval in normal men', *Clinical Physiology*, **18**(6), 570–575, (1998).

[6] Graham P Leese, Jixian Wang, Janice Broomhall, Paul Kelly, Andrew Marsden, William Morrison, Brian M Frier, and Andrew D Morris, 'Frequency of severe hypoglycemia requiring emergency treatment in type 1 and type 2 diabetes a population-based study of health service resource use', *Diabetes care*, **26**(4), 1176–1180, (2003).

[7] JLB Marques, E George, SR Peacey, ND Harris, IA Macdonald, T Cochrane, and SR Heller, 'Altered ventricular repolarization during hypoglycaemia in patients with diabetes', *Diabetic Medicine*, **14**(8), 648–654, (1997).

[8] J Meinhold, T Heise, K Rave, and L Heinemann, 'Electrocardiographic changes during insulin-induced hypoglycemia in healthy subjects.', *Hormone and metabolic research= Hormon-und Stoffwechselforschung= Hormones et metabolisme*, **30**(11), 694–697, (1998).

[9] Jean-Eudes Ranvier, Fabien Dubosson, Jean-Paul Calbimonte, and Karl Aberer, 'Detection of hypoglycemic events through wearable sensors', *International Workshop on Semantic Web Technologies for Mobile and Pervasive Environments*, (2016).

[10] Matthew Stenerson, Fraser Cameron, Shelby R Payne, Sydney L Payne, Trang T Ly, Darrell M Wilson, and Bruce A Buckingham, 'The impact of accelerometer use in exercise-associated hypoglycemia prevention in type 1 diabetes', *Journal of diabetes science and technology*, 1932296814551045, (2014).

[11] Matthew Stenerson, Fraser Cameron, Darrell M Wilson, Breanne Harris, Shelby Payne, B Wayne Bequette, and Bruce A Buckingham, 'The impact of accelerometer and heart rate data on hypoglycemia mitigation in type 1 diabetes', *Journal of diabetes science and technology*, **8**(1), 64–69, (2014).