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Leveraging Multi-modal User-labeled Data for Improved Accuracy in Interpretation of ECG Recordings

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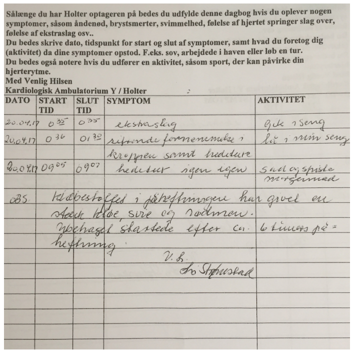
Abstract
This paper presents our preliminary design of the Reaching the Frail Elderly Patient for Optimizing Diagnosis of Atrial Fibrillation (REAFEL) system that helps to improve accuracy in interpretation of Electrocardiography (ECG) recordings by leveraging multi-modal user-labeled data and other contextual information from mobile devices. We describe the methods to collect and visualize the data, discuss the challenges associated with the project and conclude the paper by outlining future work.

Author Keywords
Personal Health Technology; mHealth; User-labeled data; Patient Reported Outcomes

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Introduction
Heart related diseases are the most common causes of death worldwide [16]. The Electrocardiography (ECG) is a standard, low-cost, noninvasive, and effective tool for diagnosis and classification of heart rhythm disorders, also known as arrhythmias [4]. A number of systems have previously been developed using different techniques to record, auto-detect and classify heart rhythm


Sålænge du har Holter optageren på bedes du udfylde denne dagbog hvis du oplever nogen symptomer, såsom åndenød, brystsmerter, svimmelhed, følelse af hjertet springer slag over, følelse af ekstraslag osv..
Du bedes skrive dato, tidspunkt for start og slut af symptomer, samt hvad du foretog dig (aktivitet) da dine symptomer opstod. F.eks. sov, arbejdede i haven eller løb en tur.
Du bedes også notere hvis du udfører en aktivitet, såsom sport, der kan påvirke din hjerterytme.
Med Venlig Hilsen
Kardiologisk Ambulatorium Y / Holter

DATO	START TID	SLUT TID	SYMPTOM	AKTIVITET
20.04.17	0^{35}	0^{35}	ekstraslag	Gik i seng
20.04.17	0^{36}	01^{30}	sitrende fornemmelse i kroppen samt hedeture	lå i min seng
20.04.17	09^{05}	09^{07}	hedetur igen igen	sad og spiste morgenmad
OBS.	Klæbestoffet i påhæftningerne har givet en stærk kløe, svie og rødmen. Ubehaget startede efter ca. 6 timers på= hæftning. V.h.			

Figure 1: Patient journal

disorders [18, 8, 12]. Often these systems are inaccurate and flawed due to misinterpretation and misclassification of heart rhythm disorders [1, 3]. Some studies have indicated that continuous monitoring of ECG with contextual information is beneficial to improve accuracy in interpretation of heart rhythm disorders and prediction of heart related diseases [11, 13].

On the one hand, research has focused on creating robust, context-aware and intelligent systems and have shown the value of the patient's physical activity and other contextual information from smartphone sensors to improve monitoring, detection, and classification of heart rhythm disorders [11, 2, 13, 7]. On the other hand, studies have supported the need for assessment of user-labeled data (ULD) such as Patient reported outcome (PRO) [1] in heart related disease management [14, 5] because PROs can provide a better representation of a patient's health status by "providing meaningful information that complements other clinical and physiological information or, in appropriate cases, be used in lieu of clinical and physiological endpoints" [15]. However, limited research has been done to leverage PROs and other contextual information from smartphone sensors with ECG data for better prediction and classification of heart rhythm disorders.

In this context, we are designing a system called Reaching the Frail Elderly Patient for Optimizing Diagnosis of Atrial Fibrillation (REAFEL)[2] that collects, processes and visualizes ECG, contextual, and PRO data from the patient. The collected data will provide context and completeness to help improve accuracy in interpretation of ECG data for early detection of heart rhythm disorders.

Preliminary Design

To understand how the ECG data can be contextualized and made easy to interpret, we conducted a user-centered design process at a large Danish University Hospital in Copenhagen. Participants in the meetings were cardiologists, electro-physiologist, nurses, medical interns, UX designers, and computer scientists. We explored the systems they are currently using to collect and analyze the ECG data.

Based on these observations and design meetings, an initial outline of the system was drawn, as shown in Figure 2. The system has two domains of data collection:

- Multi-modal ULD — Event marks and PRO from the ECG recording device and smart-phone application (Figure 2-A)
- Contextual information — Physical activities (walking, running, cycling etc.) and physical position (sleeping, standing, sitting etc.) from the sensors in the smartphone and the ECG device (Figure 2-B)

We have incorporated the above mentioned domains to design the proposed system which aims to contribute towards the improved accuracy of ECG data interpretation. Each of the domains and their implementation in the system is explained below.

Multi-modal user-labeled data (ULD)
Although the use of PRO in the management of heart condition is common in clinical settings and have been considered valuable to contextualize the ECG data, it is underutilized and has better potential in interpretation and understanding of the patient's heart condition [14]. Currently

[1] Patient reported outcome (PRO) is defined as any report of the status of a patient's health condition that comes directly from the patient, without interpretation of the patient's response by a clinician or anyone else [5].

[2] http://www.cachet.dk/research/research-projects/reafel

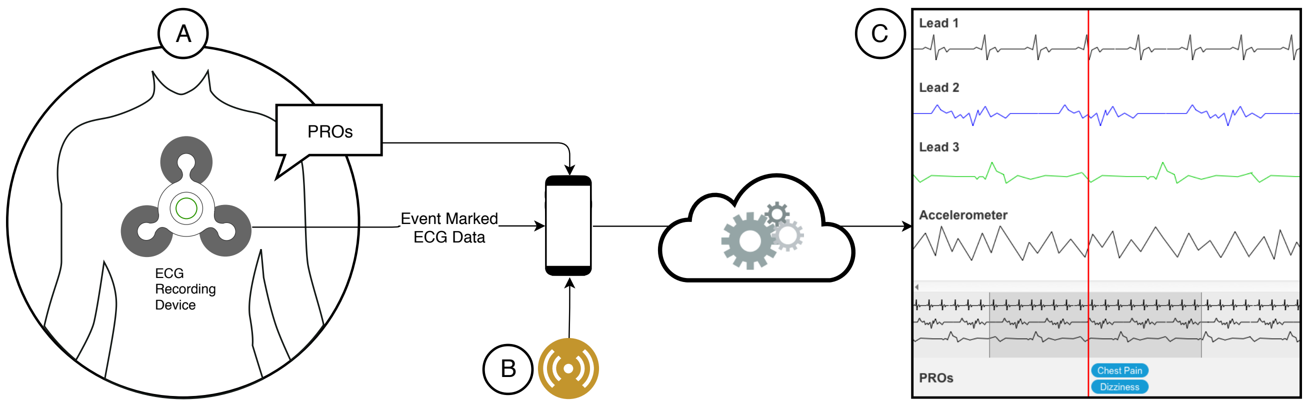


Figure 2: REAFEL system overview – (A) User-labeled data: event marked ECG data and PRO (B) Contextual information such as physical activity (walking, running, cycling etc.) from smart-phone sensors (C) ECG data visualization with contextual information.

in the hospital, PRO data from patients are collected using paper-based diaries, as shown in Figure 1. However, the clinicians stated that they could not rely on the PRO as they may be inaccurate and flawed because they are often based on patient recalls and not *in situ*, i.e., they do not represent a valid ecological momentary assessment (EMA) [10].

To address this issue, the proposed system will allow collection of event marks on ECG data and PRO *in situ*. Patients can press the button on the ECG recording device when they experience any symptoms. This creates a mark on the ECG data and prompts the patient to enter more details regarding the event via the smartphone application. The clinicians can view this information along with other contextual data from smartphone sensors, which will help to improve accuracy in interpretation of the ECG data.

Contextual information

Patient's physical activity such as walking, running, biking, etc. influence ECG data and often decrease its diagnostic quality due to motion artifacts [6]. In the current system, clinicians often have to guess certain patterns of motion artifacts based on their experience and expertise.

The cardiologist stated that physical activity of the patient is an important information to complement and interpret certain patterns of ECG data. The cardiologist gave an example of a telemetric ECG monitoring scenario where the ECG device stops sending the ECG signals because the device might have been unmounted, which could be interpreted in many ways.

In the current design, the following contextual parameters have been included by the cardiologist as relevant information in monitoring and diagnosis of heart-related episodes.

- Accelerometer and gyroscope data from the ECG device to determine the position of the patient (standing, sitting, laying down).

- Location, step counts, physical activity (e.g. walking, biking, running etc.), sleep, and external temperature from the smartphone.

This kind of data can help understand the state of the device and the patient, as well as his or her activity, sleep patterns, and surrounding environment, which is an important information to contextualize and interpret certain patterns of ECG data.

Discussion

In our design, we have identified a set of challenges in collection and visualization of multi-modal ULD and contextual information from the ECG device and smartphone sensors.

Collecting PRO in situ

Collecting PRO *in situ* may not be feasible in cases where the patients experience severe symptoms and suffer from associated physical limitations. For example, if the patient is dizzy and is about to faint, it is unlikely that the patient will be able to enter the PRO in the smartphone application. An alternative could be to allow patients to enter PRO for the marked events at a later time when they have recovered from any physical distress. However, this will overrule the idea of collecting multi-modal ULD *in situ* to avoid inaccuracy due to patient recalls. In the workshop, we would like to discuss better approaches in collecting ULD *in situ*.

To avoid manual entry of the PRO data, the smartphone application could start recording the patient's voice as soon as the event marker button is pressed. Alternatively, an algorithm could be developed to automatically start recording as soon as it detects a certain pattern of rhythm disorder. Nevertheless, both of these solutions raise privacy concerns because the smartphone application may record sound from the surroundings as well. Therefore, we would like to discuss the privacy issues and the solution in the process of data collection.

Visualizing ECG data with contextual information

An ECG recording device collects 60-100 heart beats per minute for an adult with a normal resting heart rate [9]. Analyzing large sets of ECG recordings is a challenge in itself [17]. Inclusion of PRO and other contextual information from smartphone sensors will add complexity to this. To the best of our knowledge, no previous study has investigated visualization of ECG data with PRO and contextual information to improve interpretation of ECG data. Any input and suggestion on our preliminary design will be much appreciated.

Conclusion and Future Work

To achieve the primary objective of the REAFEL project, we are designing a robust system that will help improve accuracy in interpretation of ECG recordings by collecting and visualizing multi-modal user labeled data (event marks and PRO) and other contextual information (patient's physical activities such as walking, running, cycling etc.) from smartphone devices.

Additional research is required to determine if any other information such as temperature, air pressure, humidity etc. collected via smartphone sensors are clinically relevant to improve accuracy in ECG data interpretation. Research is also needed to find the best way to visualize the heterogeneous data including PRO and other contextual information in a meaningful way so that it can help clinicians better interpret the ECG recordings.

We aim to implement a prototype of the system in a clinical setting and run a feasibility study. The study will recruit N=50 patients and 10 clinicians over the course of 12 months. This feasibility study aims to investigate system usability as well as clinical usefulness in monitoring and diagnosis of heart-related diseases.

Acknowledgements

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