Project Title:
AFCam - A Contactless System for the Detection of Atrial Fibrillation using Camera Recordings

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Tags: Atrial Fibrillation, contactless diagnostic, machine learning, Policlinico di Milano

AFCam

Project Description

Atrial Fibrillation (AF) is the most common arrhythmia that affects about 2% of the population. The prevalence of AF increases with age, from 0.5% at 40–50 years, to 5–15% at 80 years. AF is associated with increased rates of death, stroke, heart failure and hospitalizations as well as degraded quality of life, reduced exercise capacity, and left ventricular dysfunction.

AF can be paroxysmal, meaning that AF events can occur episodically and self-terminate; in such cases the clinical diagnosis is performed by Holter recordings usually for 24h or 7 days. However, because of the time irregularity of this pathology, the monitoring period could be insufficient to detect AF. The main risks of undiagnosed AF events are associated to cardioembolic stroke and AF-related complications whose management would imply higher costs for health care system.

The project aim at the development of a contactless fully automated system for screening of AF patient in different environments. The system consists of a videoPPG system, i.e. camera that detects variations of light intensity reflected

by a region of subject's face, positioned at a variable distance. From video recordings, the blood volume pulse (BVP) of peripheral arteries is extracted and processed to detect AF.

The main advantages of the proposed solution are founded in its non-invasive, fully contactless technology which can be placed anywhere, in the absence of patient's compliance requirement and in the extensive usage of portable technologies (such as mobile phones) for diagnostic purposes. From these standpoints, the project targets the development of a product for the detection of AF events both from a technological and business perspective.

From a technical point of view, the tasks which have been required to the multidisciplinary team are:

- The development of signal processing techniques to enhance videoPPG signal and to quantify its properties
- The application of machine learning techniques to classify pathological (AF, other arrhythmia and healthy patient) and non-pathological status on the base of measured videoPPG signal
- The recruitment of AF patients at Istituto Policlinico Maggiore Ca' Granda (Milan) for the statistical testing and validation of the developed algorithm.

From a business and design perspective, the tasks team have been required to develop are:

- The definition of product requirement, characteristics and design;
- The definition of a mock business plan and prototype of the service.

The result of the team is then a complete technical flow, encompassing computer vision, signal processing and machine learning topics, which has led to the effective contactless detection of AF events. The technical product and its requirements are completed by a market study and the consequent creation of an innovative business model for the commercialization of the algorithm. The product is presented under the form of a prototype site.

Tasks and Skills

The composite structure of the project has led to the distinction of three main sectors which are consequently treated by different sub-teams.

Computer Vision

Alessia Botta: Literature analysis of the face detection and face tracking algorithms, requirement analysis and corresponding technical specifications for the computer vision system.

Gian Franco Piredda: Implementation of the face detection and face tracking algorithms in Matlab and C++ and quantitative benchmarking.

Nicolò Capobianco: Implementation of the face detection and face tracking algorithms in OpenCV and computational optimization.

Signal Processing

Claudia D'Ettorre: Literature analysis of pre-processing algorithms for BVP signal extraction from video recordings, implementation of BVP extraction algorithms in Matlab and quantitative evaluation.

Giacomo D'Alessandro: Literature analysis of features extracted from BVP signals, computation of the selected features in Matlab, quantitative benchmarking.

Andrea Mariani: Literature analysis of classification algorithms in biostatistics, implementation in Matlab and quantitative evaluation.

Business Modelling and Design

Anindya Fitriyanti: Ethnographic research, user experience and user design of the formulated service.

Luca Talenti: Market analysis, creation of a business model for the commercialization of the formulated service, business plan redaction.

Abstract

Atrial fibrillation (AF) is an arrhythmia due to irregular propagation of electric impulse in the atria. This disease is diffused in about the 2% of the population and negatively affects the life conditions of pathological patients, leading oftentimes to heart strokes and being expensive to treat for the healthcare system. It is proved that an early detection of the disease highly improves life expectancy and conditions while reducing the related costs. In this study, it is developed a contactless solution for the detection of atrial fibrillation from video recordings. The solution relies on the RGB imaging approach, which starting from a video recording of the patient's face can detect the Blood Volume Pressure (BVP) signal and consequently prove the presence of AF. For this purpose, five technological phases are distinguished: face detection, face tracking, pre-processing of the signal, feature selection and classification of the signal among AF, healthy and other arrhythmia. For each of the five phases, a literature review is developed for identifying the technological alternatives. The different alternatives undergo a process of quantitative benchmarking. The final solution for face detection and tracking is developed in C++ exploiting recently developed libraries of OpenCV. The following three phases, proper of signal processing and machine learning, target the maximization of correct diagnosis. The Zero-phase Component Analysis is found as the most effective in extracting the BVP signal. On the BVP signal, twenty-six features are computed. These features are finally classified by a K nearest neighbors classifier, evaluated as the most efficient in distinguishing between AF, healthy and other arrhythmia patients. The developed solution is embedded in a two-sided platform targeting the vast public and corporations, providing a business plan and the design of the service. The provided solution is consequently innovative for the method exploited as well as for the business model creation it is inserted in.

Understanding the Problem

Atrial fibrillation (AF) has, in the last decades, received increasing attention for the social and economic burdens it represents. Indeed, its diffusion in developed countries is doomed to rise in the next years because of the ageing population. Furthermore, the heavy treatments and continuous follow-up AF patients are subjected to enhance the necessity from institutions, but also individuals, to find innovative ways in dealing with the disease. In Italy, the real extent of this pathology, although presenting an increasing trend, has still to be uncovered both from a demographic and economic dimension.

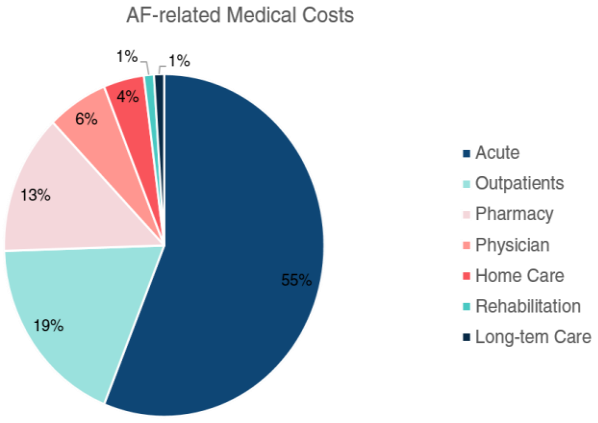

Figure 1 Breakdown of AF-related medical costs.

Several studies have proved how an early detection of the pathology combined with simple, accessible technologies can lead to a consistent lowering of this burden from a social and economic perspective. This is even more true considering that current diagnosis is based on electrocardiography, a process which requires the presence of technical staff to be performed and physicians to analyze the results.

The extent of actors concerned with AF is large, ranging from actual and potential patients to physicians, cardiologists and the healthcare system. Their needs have been studied from both primary, such as interviews and questionnaires, and secondary resources (articles, related webpages and forums). The requirement research pinpointed how a flexible, cheap, non-invasive and permeant diagnostic tool is needed for an optimal and simple measurement of the disease even in problematic settings or in sensitive patients.

Figure 2 Identikits of the main stakeholders.

For this reason, the objective of the study is is the design of an algorithm for an accurate contactless diagnosis and tracking of AF based on cutting-edge techniques and its embedding in an end-to-end viable service potentially releasable to the vast public.

Exploring the Opportunities

A contactless solution would allow the subject to behave normally without being aware of the investigation so as to obtain reliable measures without any emotional and psychological influence. Furthermore, no major contactless product or service is commercialized on the market. Indeed, other than the time-consuming and expensive ECG, just another major solution is proposed on the market: Kardia. This product, offered by AliveCor and recognized by the English healthcare system, can track an ECG from the fingertips of the user while providing diagnostics on the extracted signal. Nonetheless, such a solution can be considered as expensive for non-pathological patients who need sporadic measurements.

Given this setting, out of the contactless methodologies present in literature, the RGB imaging approach is chosen since proved to be implementable in portable devices, such as laptops and smartphones, consequently not requiring any additional product to be used. Such a technique relies on the extraction of the Blood Volume Pulse (BVP) from

face video recordings. This signal, even if less informative than the ECG, can detect the interbeat interval together with some other phase of the heart cycle.

Figure 3 Comparison of ECG and BVP signals.

This methodology is at early stage of development and its implementation is composed of five phases, related to five different technological choices:

- Face detection: face recognition and identification of the regions of interest (ROIs) in the target face;
- Face tracking: regions of interest tracking and extraction of RGB signals from the image;
- Pre-processing: extraction of the BVP signal from the RGB signals;
- Feature selection: selection of the features from the BVP signal;
- Classification: starting from the selected features, the algorithm should be able to discriminate among AF, healthy and another arrhythmia.

Each of the phases undergoes a literature review for understanding the latest advancements in the field and for creating a nurtured pool of options. The different sets are then analyzed and evaluated for arriving, in each of the phases separately, to an optimal choice, both from a technological point of view and from users' requirement perspective.

Generating a Solution

A deep evaluation of the face detection and tracking algorithms has been performed to overcome some present challenges in current heart monitoring techniques. As result, two different programming languages for algorithm implementation have been identified in Matlab and C++. These solutions differ substantially in some key parameters: computational speed, motion robustness, portability and ease of implementation. Both have been tested finding C++ more time-efficient and suitable for mobile devices. A further benefit of the second version is identified in the possibility of exploiting the potentiality of OpenCV library, an open source library for real-time computer vision. Several self-recorded videos that include different face movement and facial expression have been analysed for the algorithm validation.

Figure 4 Identification of the regions of interest.

For the last three phases, signals have been recorded from 69 subjects recruited from hospitalized patients at Ospedale Maggiore Policlinico in Milan. Results obtained from different techniques have been compared to the standard ECG results. For the pre-processing phase, the method able to detect the most reliable BVP (defined as the most consistent with the corresponding ECG) from the video recording has been retained and it is recognized in the Zero-phase Component Analysis. Once the BVP is obtained, several features are extracted from it. These are found in literature and belong to four groups: time domain indexes, spectral analysis indexes, non-linear indexes and shape analysis features. Each of them has a defined range of values and properties for the identification and the distinction of patients in AF, healthy or other arrhythmias. Finally, from the selected features, the algorithm should perform a classification between healthy individuals, AF-patients and patients with other arrhythmias. The selection of the classification methods considers seven different methodologies (K nearest neighbours, neural networks, classification trees, support vector machine, fit discriminant analysis classifier, naive bayes classifier and classification ensembles) and evaluates them according to the accuracy, this is to say the rate of correctly classified individuals out of the whole sample. Out of the seven methods, K nearest neighbours displays the highest overall accuracy (higher than 80%). Furthermore, this method achieves the highest accuracy just considering three features.

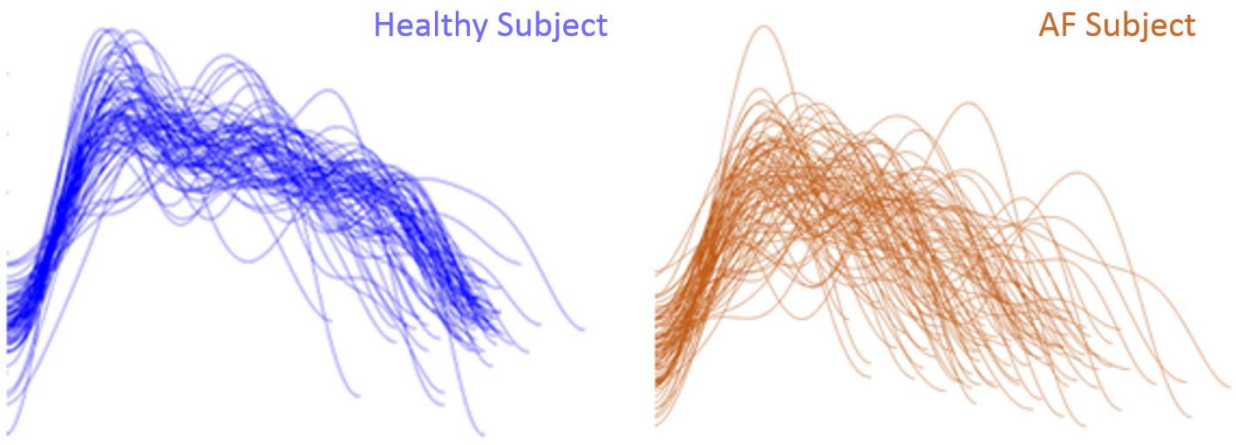

Figure 5. Difference in BVP between and AF patients and healthy individuals.

AFCam is then conceived as an internet and app-based two-sided platform addressed to consumers on one side and corporations on the other side. The two-sided platform provides individuals with the possibility to track their heart rate and BVP signal without need of contact, enabling the discovery of arrhythmias, especially AF, and the prevention of stress conditions. From the side of the corporations, a personalized and extendable contactless service is provided, giving the possibility to both employees and employers to track their own and their workers' conditions. Together with the conception of the business model, a business plan on three years (hypothetically 2017-2019) is redacted on a mock start-up considering also the strategy, the organization, financial projections and risk and key factors associated with the business. A user interface of the internet-based service is also formulated for illustrative purposes.

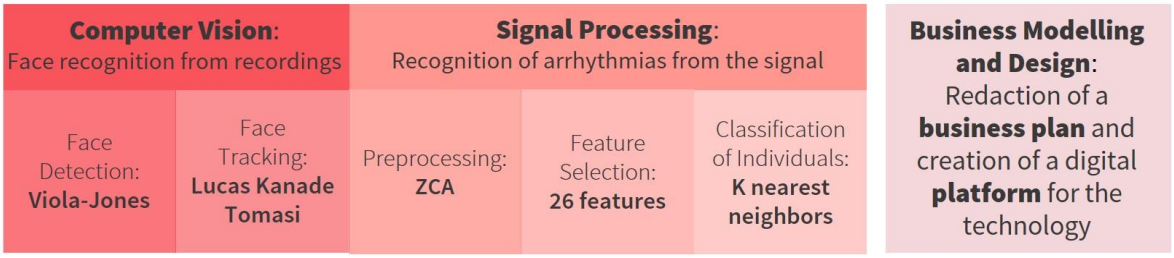

Figure 6. Technology and business decisions by phase.

The provided solution not only has undergone a scientific testing but it exploits cutting-edge methods both in computer vision, with optimized algorithm published in 2017, and in signal processing. In this latter field, the validity of the study has led to publication of a conference paper at CINC 2017. From a business side, new business models enabled by digital channels, such as two-sided platforms, are adopted, differentiating substantially the proposed service from the ones on the market.

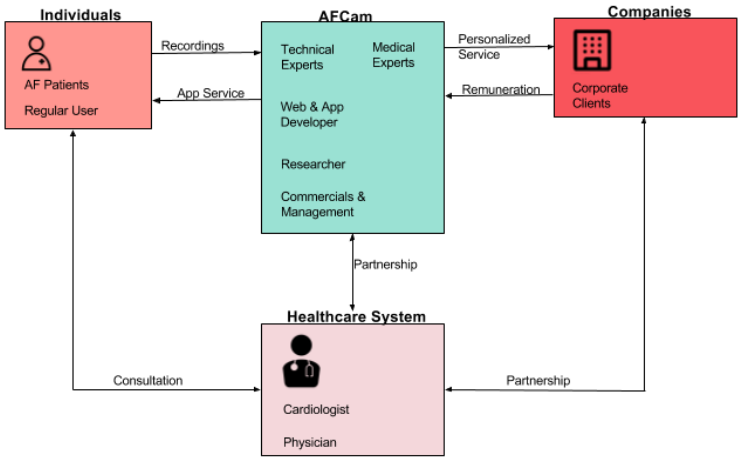

Figure 7. Scheme of the business model actors and functions.

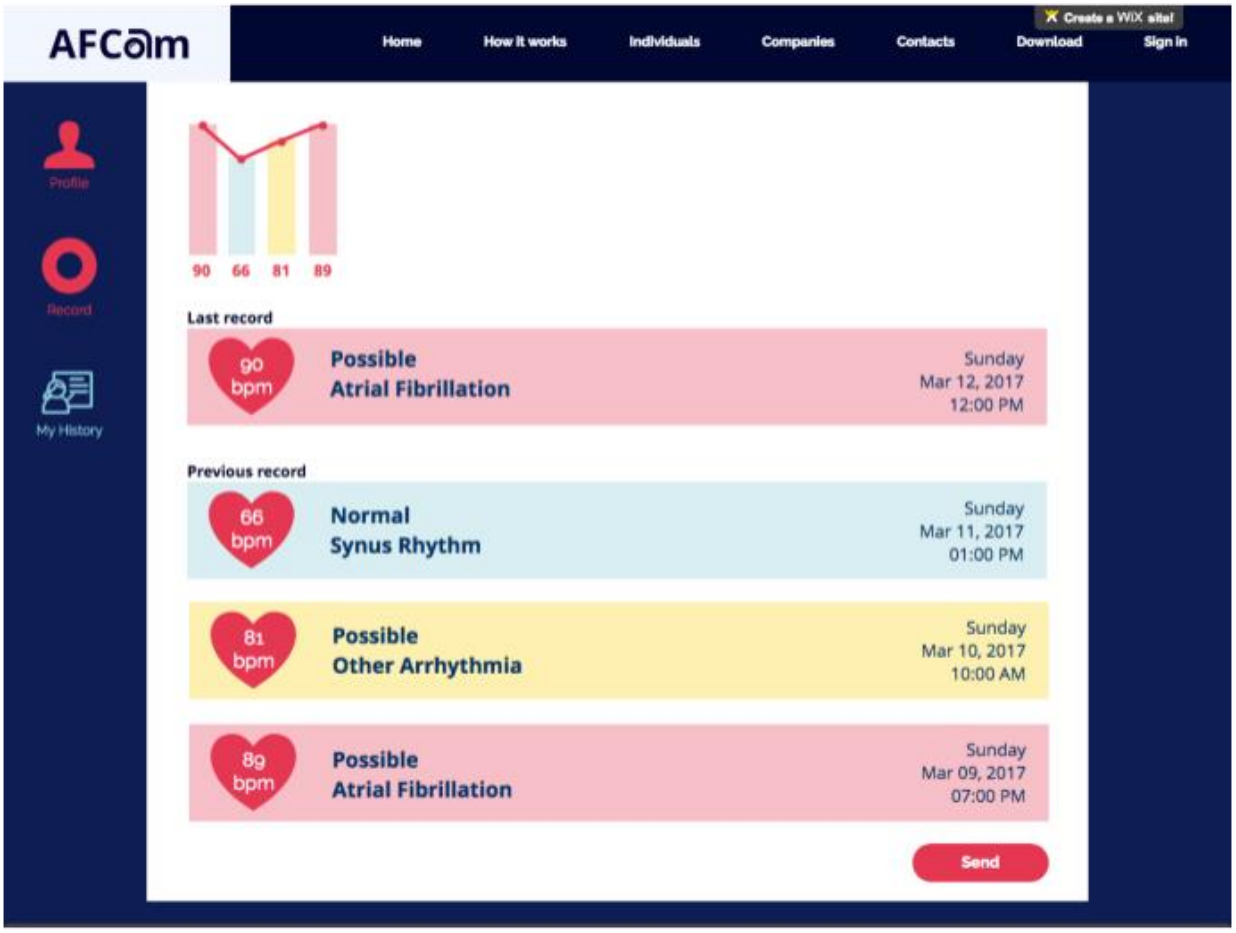

Figure 8 Design of the platform.

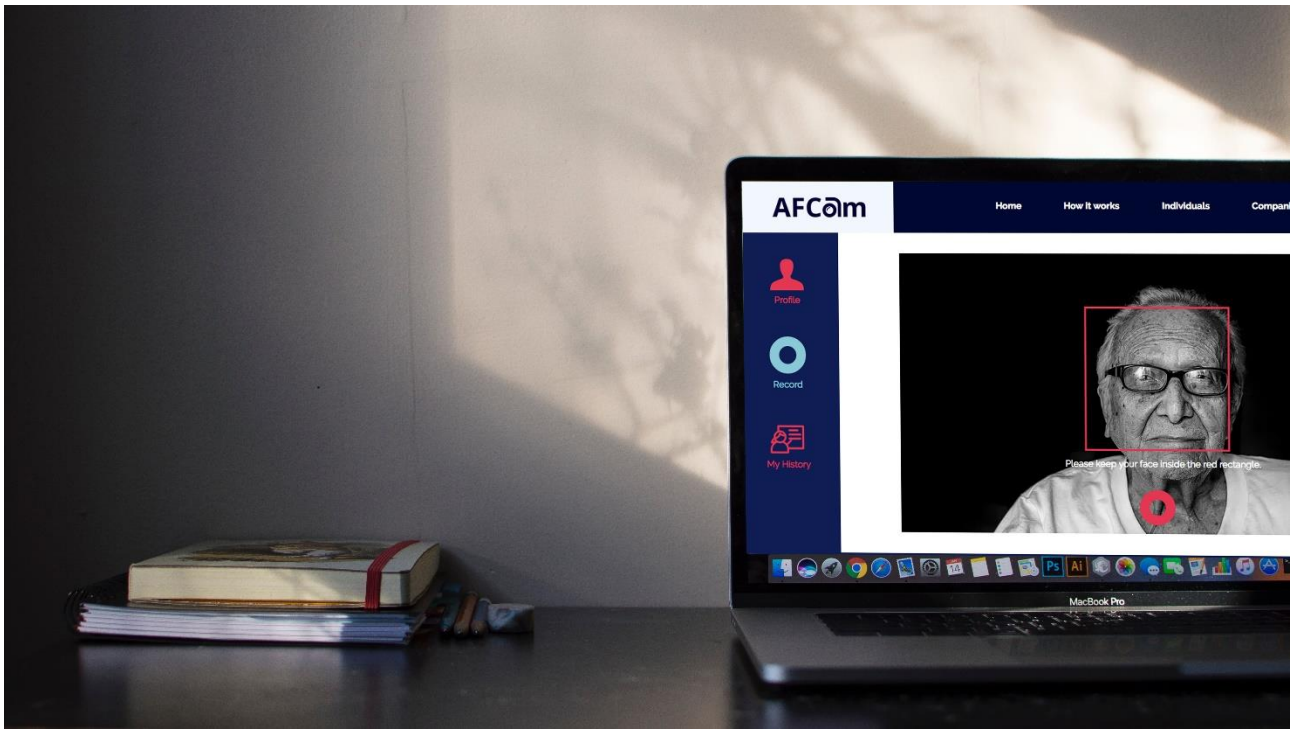

Figure 9 The AFCam platform design.

Main Bibliographic References

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Additional Material

AFCam Website – User Design: http://anindyafitriyanti.wixsite.com/afcam

Mock Business Plan: https://drive.google.com/open?id=0B-TJDwOWvawXdW9mNjBoRE12bTA