Recent Studies on Atrial Fibrillation using commercial smartwatches

Summary

The number of smartwatches dramatically increased in recent years. Most of the smartwatches are capable of collecting photoplethysmography (PPG) data with high accuracy. This capability has led several academic studies and researches focusing on detecting, diagnosing or screening heart diseases such as Atrial Fibrillation, Atrioventricular Block, Sinus Bradycardia and Sinus Tachycardia.

These studies are conducted in several countries such as the USA, Switzerland and Netherlands, and supported by some of the smartwatch manufacturers such as Apple Watch and Samsung.

We have listed 10 studies which focused on Atrial Fibrillation using commercial smartwatches since 2018. These detailed include detailed information about:

- Clinical Trials
- Data Collection Methods and User Consents
- Smartwatches, Smartphones or other devices where the data is gathered from
- Data processing or data preparation steps
- Machine Learning and Deep Learning models
- Measuring the accuracy of the proposed models
- Constraints and challenges that are still to be addressed

1- Passive Detection of Atrial Fibrillation Using a Commercially Available Smartwatch

Tison, Geoffrey H., et al. "Passive detection of atrial fibrillation using a commercially available smartwatch." JAMA cardiology3.5 (2018): 409-416.

OBJECTIVE

To develop and validate a deep neural network to detect AF using smartwatch data.

DESIGN, SETTING, AND PARTICIPANTS

In this multinational cardiovascular remote cohort study coordinated at the University of California, San Francisco, smartwatches were used to obtain heart rate and step count data for algorithm development. A total of 9750 participants enrolled in the Health eHeart Study and 51 patients undergoing cardioversion at the University of California, San Francisco, were enrolled between February 2016 and March 2017. A deep neural network was trained using a method called heuristic pretraining in which the network approximated representations of the R-R interval (ie, time between heartbeats) without manual labeling of training data. Validation was performed against the reference standard 12-lead electrocardiography (ECG) in a separate cohort of patients undergoing cardioversion. A second exploratory validation was performed using smartwatch data from ambulatory individuals against the reference standard of self-reported history of persistent AF. Data were analyzed from March 2017 to September 2017.

MAIN OUTCOMES AND MEASURES

The sensitivity, specificity, and receiver operating characteristic C statistic for the algorithm to detect AF were generated based on the reference standard of 12-lead ECG–diagnosed AF.

RESULTS

Of the 9750 participants enrolled in the remote cohort, including 347 participants with AF, 6143 (63.0%) were male, and the mean (SD) age was 42 (12) years. There were more than 139 million heart rate measurements on which the deep neural network was trained. The deep neural network exhibited a C statistic of 0.97 to detect AF against the reference standard 12-lead ECG–diagnosed AF in the external validation cohort of 51 patients undergoing cardioversion; sensitivity was 98.0% and specificity was 90.2%. In an exploratory analysis relying on self-report of persistent AF in ambulatory participants, the C statistic was 0.72; sensitivity was 67.7% and specificity was 67.6%.

CONCLUSIONS AND RELEVANCE

This proof-of-concept study found that smartwatch photoplethysmography coupled with a deep neural network can passively detect AF but with some loss of sensitivity and specificity against a criterion-standard ECG. Further studies will help identify the optimal role for smartwatch-guided rhythm assessment.

2- End-to-end Deep Learning from Raw Sensor Data: Atrial Fibrillation Detection using Wearables

Gotlibovych, Igor, et al. "End-to-end Deep Learning from Raw Sensor Data: Atrial Fibrillation Detection using Wearables." arXiv preprint arXiv:1807.10707 (2018).

DATA COLLECTION

The authors collaborated with the University of California, San Francisco (UCSF) Division of Cardiology to record a range of signals as patients undergo cardioversion - a medical procedure that restores normal sinus rhythm (NSR) in patients with AFib through electric shocks.

METHOD AND RESULT

A convolutional-recurrent neural network architecture with long short-term memory for real-time processing and classification of digital sensor data is proposed. The network implicitly performs typical signal processing tasks such as ltering and peak detection, and learns time-resolved embeddings of the input signal. A prototype multi-sensor wearable device is used to collect over 180 h of photoplethysmography (PPG) data sampled at 20 Hz, of which 36 h are during atrial fibrillation (AFib). End-to-end learning is used to achieve state-of-the-art results in detecting AFib from raw PPG data. For classification labels output every 0.8 s, an area under ROC curve of 0.9999 is demonstrated, with false positive and false negative rates both below 2×10^{-3}. This constitutes a significant improvement on previous results utilising domain-specific feature engineering, such as heart rate extraction, and brings large-scale atrial fibrillation screenings within imminent reach.

3- Detection of atrial fibrillation with a smartphone camera: first prospective, international, two-centre, clinical validation study (DETECT AF PRO)

Brasier, Noé, et al. "Detection of atrial fibrillation with a smartphone camera: first prospective, international, two-centre, clinical validation study (DETECT AF PRO)." Ep Europace 21.1 (2018): 41-47.

This study is completed in University Hospital, Basel, Switzerland.

OBJECTIVE

Early detection of atrial fibrillation (AF) is essential for stroke prevention. Emerging technologies such as smartphone cameras using photoplethysmography (PPG) and mobile, internet-enabled electrocardiography (iECG) are effective for AF screening. This study compared a PPG-based algorithm against a cardiologist's iECG diagnosis to distinguish between AF and sinus rhythm (SR).

METHODS AND RESULTS

In the prospective, two-centre, international, clinical validation study, they recruited in-house patients with presumed AF and matched controls in SR at two university hospitals in Switzerland and Germany. In each patient, a PPG recording on the index fingertip using a regular smartphone camera followed by iECG was obtained. Photoplethysmography recordings were analysed using an automated algorithm and compared with the blinded cardiologist'S iECG diagnosis. Of 672 patients recruited, 80 were excluded mainly due to insufficient PPG/iECG quality, leaving 592 patients (SR: n = 344, AF: n = 248). Based on 5 min of PPG heart rhythm analysis, the algorithm detected AF with a sensitivity of 91.5% (95% confidence interval 85.9–95.4) and specificity of 99.6% (97.8–100). By reducing analysis time to 1 min, sensitivity was reduced to 89.9% (85.5–93.4) and specificity to 99.1% (97.5–99.8). Correctly classified rate was 88.8% for 1-min PPG analysis and dropped to 60.9% when the threshold for the analysed file was set to 5 min of good signal quality.

CONCLUSION

This is the first prospective clinical two-centre study to demonstrate that detection of AF by using a smartphone camera alone is feasible, with high specificity and sensitivity. Photoplethysmography signal analysis appears to be suitable for extended AF screening.

CLINICAL TRIAL

ClinicalTrials.gov, number NCT02949180, https://clinicaltrials.gov/ct2/show/NCT02949180.

4- Atrial Fibrillation Detection Using a Novel Cardiac Ambulatory Monitor Based on Photo-Plethysmography at the Wrist

Bonomi, Alberto G., et al. "Atrial Fibrillation Detection Using a Novel Cardiac Ambulatory Monitor Based on Photo-Plethysmography at the Wrist." Journal of the American Heart Association 7.15 (2018): e009351.

This study is completed in Netherlands, TU/e, Catharina Hospital, and Philips Electronics Nederland B.V.. This study examined the accuracy of a novel approach for AF detection using photo-plethysmography signals measured from a wrist-based wearable device.

Methods and Results

ECG and contemporaneous pulse data were collected from 2 cohorts of AF patients: AF patients (n=20) undergoing electrical cardioversion (ECV) and AF patients (n=40) that were prescribed for 24 hours ECG Holter in outpatient settings (HOL). Photo-plethysmography and acceleration data were collected at the wrist and processed to determine the inter-pulse interval and discard inter-pulse intervals in presence of motion artifacts. A Markov model was deployed to assess the probability of AF given irregular pattern in inter-pulse interval sequences. The AF detection algorithm was evaluated against clinical rhythm annotations of AF based on ECG interpretation. Photo-plethysmography recordings from apparently healthy volunteers (n=120) were used to establish the false positive AF detection rate of the algorithm. A total of 42 and 855 hours (AF: 21 and 323 hours) of photo-plethysmography data were recorded in the ECV and HOL cohorts, respectively. AF was detected with >96% accuracy (ECV, sensitivity=97%; HOL, sensitivity=93%; both with specificity=100%). Because of motion artifacts, the algorithm did not provide AF classification for 44±16% of the monitoring period in the HOL group. In healthy controls, the algorithm demonstrated a <0.2% false positive AF detection rate.

Conclusions

A novel algorithm analyzing pulse data from a wrist-wearable device can accurately detect pulse irregularities associated with AF. Findings suggest that wrist-based wearables capable of pulse monitoring can be used as long-term monitors for AF and thereby enhance detection of paroxysmal AF and assessment of AF burden among patients affected by this dysrhythmia.

5- Diagnostic Performance of a Smartphone-Based Photoplethysmographic Application for Atrial Fibrillation Screening in a Primary Care Setting

Chan, Pak-Hei, et al. "Diagnostic performance of a smartphone-based photoplethysmographic application for atrial fibrillation screening in a primary care setting." Journal of the American Heart Association 5.7 (2016): e003428.

Background

Diagnosing atrial fibrillation (AF) before ischemic stroke occurs is a priority for stroke prevention in AF. Smartphone camera–based photoplethysmographic (PPG) pulse waveform measurement discriminates between different heart rhythms, but its ability to diagnose AF in real-world situations has not been adequately investigated. They sought to assess the diagnostic performance of a standalone smartphone PPG application, Cardiio Rhythm, for AF screening in primary care setting.

Methods and Results

Patients with hypertension, with diabetes mellitus, and/or aged ≥65 years were recruited. A single-lead ECG was recorded by using the AliveCor heart monitor with tracings reviewed subsequently by 2 cardiologists to provide the reference standard. PPG measurements were performed by using the Cardiio Rhythm smartphone application. AF was diagnosed in 28 (2.76%) of 1013 participants. The diagnostic sensitivity of the Cardiio Rhythm for AF detection was 92.9% (95% CI] 77–99%) and was higher than that of the AliveCor automated algorithm (71.4% [95% CI 51–87%]). The specificities of Cardiio Rhythm and the AliveCor automated algorithm were comparable (97.7% [95% CI: 97–99%] versus 99.4% [95% CI 99–100%]). The positive predictive value of the Cardiio Rhythm was lower than that of the AliveCor automated algorithm (53.1% [95% CI 38–67%] versus 76.9% [95% CI 56–91%]); both had a very high negative predictive value (99.8% [95% CI 99–100%] versus 99.2% [95% CI 98–100%]).

Conclusions

The Cardiio Rhythm smartphone PPG application provides an accurate and reliable means to detect AF in patients at risk of developing AF and has the potential to enable population-based screening for AF.

6- Ambulatory Atrial Fibrillation Monitoring Using Wearable Photoplethysmography with Deep Learning

Voisin, Maxime, et al. "Ambulatory Atrial Fibrillation Monitoring Using Wearable Photoplethysmography with Deep Learning." arXiv preprint arXiv:1811.07774 (2018).

This study is done jointly with Samsung Strategy and Innovation Center and Stanford University.

Data collection

All PPGs are recorded using a Samsung wrist-wearable device with a sampling frequency of 20 Hz. The device also records tri-axial acceleration, which is used in Section 4.2 to evaluate the model's robustness to motion artifacts. In the clinician-annotated dataset, the reference ECG is collected from a single-lead, continuous monitoring patch with a sampling frequency of 500Hz. Each ECG is fully annotated by an ECG technician. The expert technician highlights segments of the continuous signal and marks them as corresponding to one of 10 rhythm classes: 8 heart arrhythmias, normal sinus rhythm and noise. All rhythms were labeled from their corresponding onset to offset, resulting in a full segmentation of the ECG. The noise label is assigned when it is impossible to identify the underlying rhythm from the ECG.

Results

They develop an algorithm that accurately detects Atrial Fibrillation (AF) episodes from photoplethysmograms (PPG) recorded in ambulatory free-living conditions. We collect and annotate a dataset containing more than 4000 hours of PPG recorded from a wrist-worn device. Using a 50-layer convolutional neural network, we achieve a test AUC of 95% and show robustness to motion artifacts inherent to PPG signals. Continuous and accurate detection of AF from PPG has the potential to transform consumer wearable devices into clinically useful medical monitoring tools.

7- Sensor analytics for interpretation of EKG signals

Kalgotra, Pankush, et al. "Sensor analytics for interpretation of ekg signals." Expert Systems with Applications (2019).

Motivation and Objectives

Smartphones are emerging as personal fitness assistants, collecting data through in-built or external sensors. The next frontier for these devices is to use advanced sensors and machine

learning algorithms to offer more personalized and advanced medical assessments. Along these lines, the objective of this paper is to develop a multi-label classification model to detect heart complications through electrocardiograms (EKGs) collected by an FDA-approved single-lead EKG sensor attached to a smartphone. The EKG sensor produces a standard EKG chart, but for such a sensor to be useful to a consumer, an interpretation of the graph is necessary.

Materials and Method

We adapt a machine-learning approach to detect multiple heart conditions simultaneously from the generated EKG graph. Three different multi-label machine learning models (binary relevance, label powerset and multi-perceptron neural network) were built and compared to categorize five different heart states: Normal, Atrial Fibrillation, Atrioventricular Block, Sinus Bradycardia and Sinus Tachycardia. The binary relevance model was selected based on the accuracy.

Results and Implications

The model generated rules inductively from the data to interpret nine out of every ten heart conditions correctly. Our model is being adapted for commercial use by a company (as a part of their App) that markets the EKG sensor for smartphones. Our model is usable in a cardiovascular disease alert expert system that will potentially allow users to monitor their heart health continuously and prevent a serious illness by providing this information in the early stages.

8- WATCH AF Trial: SmartWATCHes for Detection of Atrial Fibrillation

Dörr, Marcus, et al. "WATCH AF Trial: SmartWATCHes for Detection of Atrial Fibrillation." JACC: Clinical Electrophysiology (2018).

Similar to [3], this study is completed in University Hospital, Basel, Switzerland.

Objectives

The WATCH AF (SmartWATCHes for Detection of Atrial Fibrillation) trial compared the diagnostic accuracy to detect atrial fibrillation (AF) by a smartwatch-based algorithm using photoplethysmographic (PPG) signals with cardiologists' diagnosis by electrocardiography (ECG).

Background

Timely detection of AF is crucial for stroke prevention.

Methods

In this prospective, 2-center, case-control trial, a PPG pulse wave recording using a commercially available smartwatch was obtained along with Internet-enabled mobile ECG in 672 hospitalized subjects. PPG recordings were analyzed by a novel automated algorithm. Cardiologists' diagnoses were available for 650 subjects, although 142 (21.8%) datasets were not suitable for PPG analysis, among them 101 (15.1%) that were also not interpretable by the automated Internet-enabled mobile ECG algorithm, resulting in a sample size of 508 subjects (mean age 76.4 years, 225 women, 237 with AF) for the main analyses.

Results

For the PPG algorithm, we found a sensitivity of 93.7% (95% confidence interval [CI]: 89.8 to 96.4), a specificity of 98.2% (95% CI: 95.8 to 99.4), and 96.1% accuracy (95% CI: 94.0 to 97.5) to detect AF.

Conclusions

The results of the WATCH AF trial suggest that detection of AF using a commercially available smartwatch is in principle feasible, with very high diagnostic accuracy. Applicability of the tested algorithm is currently limited by a high dropout rate as a result of insufficient signal quality. Thus, achieving sufficient signal quality remains challenging, but real-time signal quality checks are expected to improve signal quality. Whether smartwatches may be useful complementary tools for convenient long-term AF screening in selected at-risk patients must be evaluated in larger population-based samples.

9- Rationale and design of a large-scale, app-based study to identify cardiac arrhythmias using a smartwatch: The Apple Heart Study

Turakhia, Mintu P., et al. "Rationale and design of a large-scale, app-based study to identify cardiac arrhythmias using a smartwatch: The Apple Heart Study." American heart journal 207 (2019): 66-75.

This is the most comprehensive study on cardiac arrhythmias using a smart watch. These parties are involved in the study:

- Center for Digital Health, Stanford University Stanford, CA
- VA Palo Alto Health Care System, Palo Alto, CA

- Quantitative Sciences Unit, Stanford University, Stanford, CA
- Stanford Center for Clinical Research, Stanford University, Stanford, CA
- Information Resources and Technology, Stanford University, Stanford, CA
- Apple Inc. Cupertino, CA
- Lankenau Heart Institute and Jefferson Medical College, Philadelphia, PA
- University of Colorado School of Medicine, Denver, CO
- Division of Cardiovascular Disease, Cooper Medical School of Rowan University, Camden, NJ
- StopAfib.org, American Foundation for Women's Health, Decatur, TX
- Duke Clinical Research Institute, Duke University, Durham, NCl
- Division of Cardiovascular Medicine, Stanford University, Stanford, CA

Background

Smartwatch and fitness band wearable consumer electronics can passively measure pulse rate from the wrist using photoplethysmography (PPG). Identification of pulse irregularity or variability from these data has the potential to identify atrial fibrillation or atrial flutter (AF, collectively). The rapidly expanding consumer base of these devices allows for detection of undiagnosed AF at scale.

Methods

The Apple Heart Study is a prospective, single arm pragmatic study that has enrolled 419,093 participants (NCT03335800). The primary objective is to measure the proportion of participants with an irregular pulse detected by the Apple Watch (Apple Inc, Cupertino, CA) with AF on subsequent ambulatory ECG patch monitoring. The secondary objectives are to: 1) characterize the concordance of pulse irregularity notification episodes from the Apple Watch with simultaneously recorded ambulatory ECGs; 2) estimate the rate of initial contact with a health care provider within 3 months after notification of pulse irregularity. The study is conducted virtually, with screening, consent and data collection performed electronically from within an accompanying smartphone app. Study visits are performed by telehealth study physicians via video chat through the app, and ambulatory ECG patches are mailed to the participants.

Conclusions

The results of this trial will provide initial evidence for the ability of a smartwatch algorithm to identify pulse irregularity and variability which may reflect previously unknown AF. The Apple Heart Study will help provide a foundation for how wearable technology can inform the clinical approach to AF identification and screening.

10- Diagnostic assessment of a deep learning system for detecting atrial fibrillation in pulse waveforms

Poh, Ming-Zher, et al. "Diagnostic assessment of a deep learning system for detecting atrial fibrillation in pulse waveforms." Heart 104.23 (2018): 1921-1928.

Objective

To evaluate the diagnostic performance of a deep learning system for automated detection of atrial fibrillation (AF) in photoplethysmographic (PPG) pulse waveforms.

Methods

We trained a deep convolutional neural network (DCNN) to detect AF in 17 s PPG waveforms using a training data set of 149 048 PPG waveforms constructed from several publicly available PPG databases. The DCNN was validated using an independent test data set of 3039 smartphone-acquired PPG waveforms from adults at high risk of AF at a general outpatient clinic against ECG tracings reviewed by two cardiologists. Six established AF detectors based on handcrafted features were evaluated on the same test data set for performance comparison.

Results

In the validation data set (3039 PPG waveforms) consisting of three sequential PPG waveforms from 1013 participants (mean (SD) age, 68.4 (12.2) years; 46.8% men), the prevalence of AF was 2.8%. The area under the receiver operating characteristic curve (AUC) of the DCNN for AF detection was 0.997 (95% CI 0.996 to 0.999) and was significantly higher than all the other AF detectors (AUC range: 0.924–0.985). The sensitivity of the DCNN was 95.2% (95% CI 88.3% to 98.7%), specificity was 99.0% (95% CI 98.6% to 99.3%), positive predictive value (PPV) was 72.7% (95% CI 65.1% to 79.3%) and negative predictive value (NPV) was 99.9% (95% CI 99.7% to 100%) using a single 17 s PPG waveform. Using the three sequential PPG waveforms in combination (<1 min in total), the sensitivity was 100.0% (95% CI 87.7% to 100%), specificity was 99.6% (95% CI 99.0% to 99.9%), PPV was 87.5% (95% CI 72.5% to 94.9%) and NPV was 100% (95% CI 99.4% to 100%).

Conclusions

In this evaluation of PPG waveforms from adults screened for AF in a real-world primary care setting, the DCNN had high sensitivity, specificity, PPV and NPV for detecting AF, outperforming other state-of-the-art methods based on handcrafted features.

References

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