Performance of Noncontact Video-based Detection of Pulse Rate and Atrial Fibrillation on Personal Computers Utilizing a Webcam

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Abstract

We developed a video-based monitoring technology to detect atrial fibrillation and pulse rate to support telemedicine applications. In the past, we reported results and performance of the technology implemented on Android based devices (tablets and smartphones). Recently, the technology was implemented on the Windows operating system. In this work, we present performance results of the recent implementation over a Windows 10 laptop connected to a commercially available webcam. Our analysis is based on a clinical validation study involving 22 patients diagnosed with paroxysmal and persistent Atrial Fibrillation. Results demonstrate very high accuracy in heart rate estimation. Namely, 95% of estimated pulse rate values have no more than 5 BPM deviation from reference heart rate. In addition, specificity and sensitivity of 0.86 and 0.85 respectively are obtained when detecting atrial fibrillation. These results match those of traditionally accepted medical grade devices.

1. Introduction

Telemedicine has revolutionized the field of cardiology by bridging geographical gaps and enhancing patient care. Through secure video consultations and remote monitoring, cardiologists can now reach patients in remote areas, providing timely expertise and reducing disparities in cardiac healthcare. Specifically, patients with chronic heart conditions such as *Atrial Fibrillation* (AF) can benefit from cardiac monitoring at home, allowing timely detection of AF recurrence and trigger an intervention.

AF is a common heart rhythm disorder, characterized by rapid and irregular atrial activation. Its prevalence in the population has increased significantly and results in a broad impact on public health, especially because of the increased risk of stroke and hospitalization [1,2]. Detection of AF at an early stage of the disease is likely to improve patients' prognoses and slow disease progression. Once patients are diagnosed with AF, they are typically prescribed medication to regulate their heart activity. Persistent monitoring of patients' HR is therefore important to assess the impact of such drugs and perform drug titration.

The gold standard device for detecting AF and measuring HR is the *ElectroCardioGram* (ECG). However, its use away from a healthcare facility is problematic and cumbersome. An ECG holter or patch would need to be send to the patient and electrodes would have to be professionally placed on the skin at exact locations after shaving the target areas. These restrictions makes ECG a problematic solution for telemedicine applications, where the patient and healthcare professionals are far apart. An alternative is to use a *PhotoPlethysmoGraphy* (PPG) sensor that is much easier to attach to the skin, but still requires the use of a dedicated device sent to the patient.

Similar to traditional PPG, *VideoPlethysmoGraphy* (VPG) captures a pulsatile signal from a patient's face [3-17]. It does so by capturing the modulation of ambient light reflected from one's face due to changes in blood volume (hemoglobin) in the upper layers of the skin. VPG operating using a webcam connected to a personal computer or a laptop offer an attractive alternative to PPG and ECG devices. A remote telemedicine station is likely to already have such equipment in place to support online interaction between patient and physician. Such equipment is also likely to already be available in other public locations such as schools and even in a patient's home. It follows that a reliable VPG solution to HR and AF monitoring has the potential to increase the proliferation of telemedicine applications and decrease access disparity to cardiac monitoring services.

Past work on VPG investigated its performance compared to PPG and ECG devices. Some examples can we found in [5-9]. It was shown that under certain reasonable conditions (ambient light, stillness and camera specifications), VPG does offer a reliable alternative to PPG and ECG.

We developed a technology called HealthKam Afib (HK). HK provided cardiac monitoring in the form of *Heart Rate* (HR) measurements and AF detection using commercially available web cameras connected devices operating under the Windows platform (laptops, personal computers, etc.). This technology is scalable, cost effective

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	Female (N=16)	Male (N=44)	P-value
Age (yrs)	71 ± 8.9	66 ± 10	0.091
Weight (kg)	78 ± 19	98 ± 16	0.003
Height (m)	1.7 ± 0.081	1.8 ± 0.099	<0.001
BMI (kg/m2)	28 ± 5.8	31 ± 5.4	0.117
Syst BP (mmHg)	120 ± 18	130 ± 13	0.301
Diast BP (mmHg)	75 ± 10	80 ± 14	0.249

	Female (N=16)	Male (N=44)
AF type		
Long standing persistent	1 (6.3%)	5 (11.4%)
Paroxysmal	8 (50.0%)	17 (38.6%)
Persistent	1 (6.3%)	6 (13.6%)
Unknown	6 (37.5%)	12 (27.3%)
Permanent	0 (0%)	4 (9.1%)

Table 1: Validation study cohort statistics.

Figure 1: Experimental setup of the validation study.

and may reduce travel burden. It brings affordable, accessible, and early cardiac monitoring to remote and underserved communities, ultimately improving healthcare outcomes and reducing the impact of AF-related complications.

Using the HK Windows program, the user or caregiver initiates a 25 seconds measurement. No pictures or videos are taken in the process, so complete user privacy is preserved. Anonymized captured data is sent to the cloud, where sophisticated algorithm are used to estimate HR and detect AF. The resulting indications are sent back to the APP for presentation to the user and for tracking monitoring history.

In the past, we reported results for HK implemented on Android based devices (tablets and smartphones) [14-17]. In this work, we investigate performance of an implementation of the technology on a Windows personal computer connected to a commercially-available webcam. We attempt to validate performance on the Windows platform by making use of the algorithms as trained on the Android platform. This approach allows us to conduct a smaller clinical study to gather only validation data. The results provided by such analysis represent suboptimal performance, since performance can be improved in the future by training the algorithms using more data captured on the Windows platform. The results also provide insight to the portability of the HealthKam AFib technology across platforms and future devices.

To collect validation data, we conducted a study involving 22 subjects diagnosed with paroxysmal AF, where the subjects' HR and AF where detected in various real-world conditions including typical indoor illumination ranges, distances from the camera and lighting fixture types. Our results demonstrate that the algorithms trained on the Android platform port well to the Windows platform. 95% of estimated PR values have no more than 5 BPM deviation from the ECG HR measure. The AF detection *Receiver Operating Characteristic* (ROC) curve has an *Area under the Curve* (AuC) of 0.9 (Figure 3). Setting operating parameters similar to the S10 device results in Sensitivity (SENS) of 0.88 and Specificity (SPEC) of 0.80.

2. Methods

The validation study was conducted under safety requirements and was approved by an independent oversight committee (IRB). We used a webcam (Logitech CD950) connected to a laptop running Windows 10 OS, an ECG recorder (M5 ECG patch, Global Instrumentation, LLC, Manlius, NY, USA), and an SPO2 finger PPG sensor (MightySat Rx, Massimo, Irvine, CA, USA). Study design and logistics are described in Figure 1. We enrolled 22 paroxysmal and persistent AF patients. Table 1 presents the cohort statistics.

For each patient, measurements were conducted under 4 indoor illumination levels (50, 100, 200, and 500 lux), 3 distances (10, 20, 30 centimeters) and repeated for two typical indoor light sources (LED and incandescent). A portion of the measurements were performed after elevating the subject's HR using the elliptical machine.

HR accuracy was assessed using Bland-Altman analyses [18] with paired replicate measures based on one-way repeated ANOVA. AF detection performance was measured as an average SENS and SPEC adjusted for repeated measures and AuC taken from the ROC.

We collected 1,061 recordings from 22 AF patients (age: 67±10 years). 173 recordings were automatically discarded by our technology quality filtering algorithms due to subject motion, insufficient illumination, and face obstruction. The remaining 888 recordings (84% of all

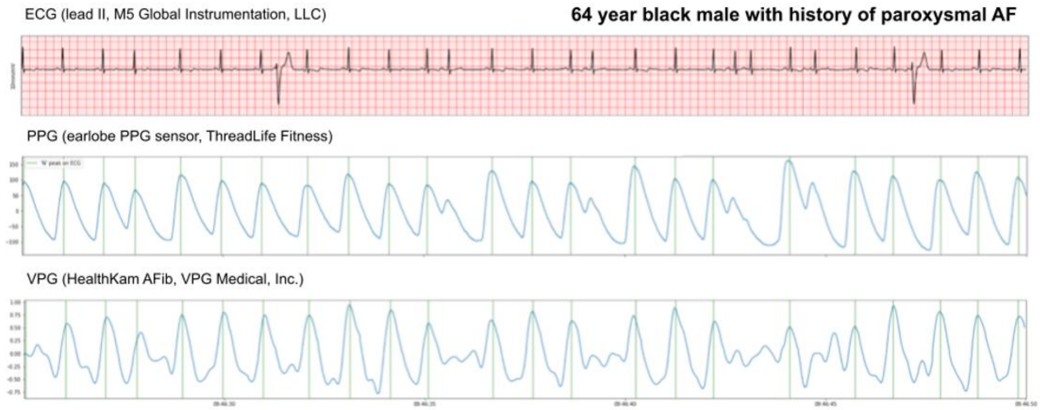

Figure 2: Example of synchronized signals captured during the validation study.

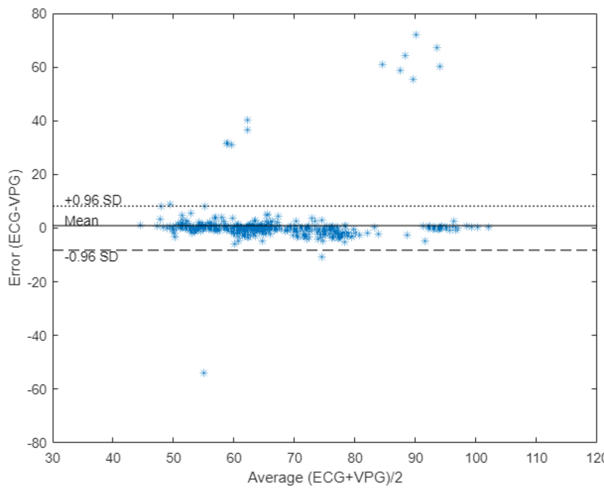

Figure 3: Bland-Altman plot assessing the agreement between video-based PR and reference HR.

recordings) were used as the validation dataset. In all recordings, the VPG signal was synchronized with the ECG signals to provide beat by beat detection and comparison.

3. Results

An example of a signal captured by the setup is presented in Figure 2. Note how the ECG, PPG and VPG signals are all aligned on a beat by beat basis and how irregularities in the ECG cardiograph are also reflected in the PPG and VPG signals.

The BA plot shown in Figure 3 exhibits unbiased estimation of HR with strong agreement to ECG. Specifically, 95% of estimated PR values have no more than 5 BPM deviation from the ECG HR measure.

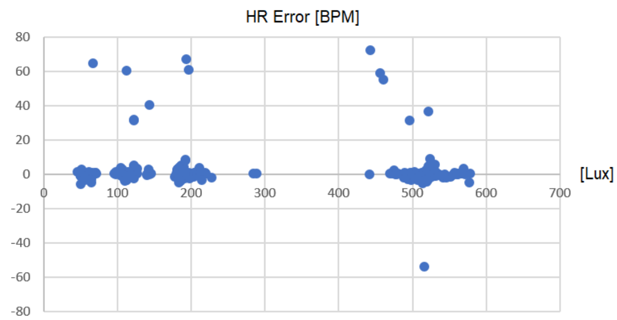

Figure 4: provides the HR accuracy across ambient illumination levels varying from 50 to 500 lux.

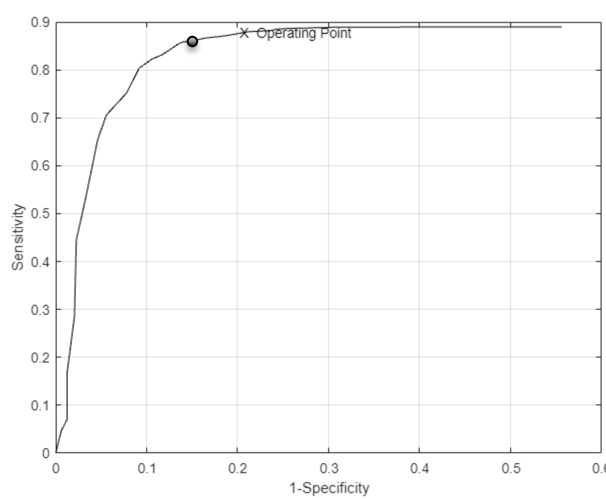

Figure 5: ROC curve assessing the accuracy of AF detection on iOS platforms. x represents the operating point using Android thresholds, while ● represents an alternative operating point.

We also present HR estimation accuracy across illumination levels in Figure 4. Note that the number of measurements increases with the illumination level, while HR accuracy is maintained across all illuminations levels.

This result shows how the HK automated quality filtering successfully discards measurements of low quality that are more prevalent under subpar illumination of the subject's face.

The AF detection ROC curve is presented in Figure 5. The AUC is 0.9. Setting operating parameters similar to those trained on the Android platform results in SENS of 0.88 and SPEC of 0.80. Note that an alternative operating point is possible that results in SENS of 0.86 and SPEC of 0.85. This level of accuracy is equivalent to that of medical grade devices.

4. Conclusion

The HealthKam AFib implementation on the Windows platform using a commercially available webcam provides medical grade technology that could be integrated into telemedicine video applications for enabling contactless measure of HR and for the detection of AF. The technology operates across a wide range of expected indoor illumination levels, light sources, distances and across all human skin complexions.

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