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SHORT-PAPER

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Tracking Radial Artery Dynamics Using Brightness-Mode Ultrasound and Video Analysis

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Abstract

Cardiovascular disease is an important concern and the evaluation of vascular health is a key element for early detection. However, continuous non-invasive measurement of vascular health is limited to clinical settings while wearable health sensing devices are lacking vascular health detection. To achieve such wearable continuous cardiovascular health measurement, better understanding about physical properties of the vascular system are needed. Towards the development of wearable continuous cardiovascular health monitoring, we developed, verified, and validated an algorithm to estimate the dynamic radius of the radial artery and estimated the arterial pulsation from brightness-mode ultrasound imaging. The algorithm was implemented using Python and MATLAB®. The algorithm was tested using a simulation environment, as well as ultrasound imaging together with continuous non-invasive arterial pressure monitoring from participants. The radial artery size and distance from surface measured was >90 % accurate. We report an informative summary from 6 participants. The radial artery radius change over time was used to estimate heart-beat rate, and showed reasonable accuracy for 5 out of 6 participants.

CCS Concepts

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**; **Empirical studies in ubiquitous and mobile computing**; • **Applied computing → Consumer health**; **Health informatics**.

Keywords

algorithm development, CNAP, image processing, physiological phenomena, verification and validation.

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1 Introduction

Cardiovascular diseases remain a leading global health challenge, with a reported economic impact of around €155 billion within the European Union in 2021 [6]. Consequently, better understanding of vascular biomechanics and improved methods to assess cardiovascular health are needed.

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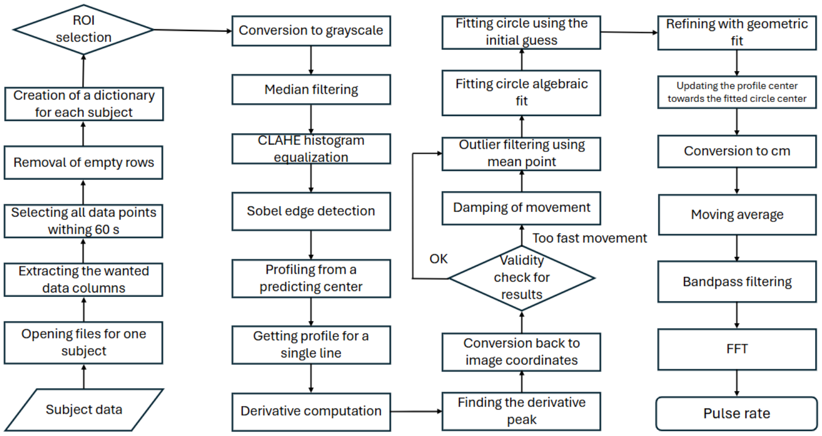

Figure 1: A flow representing the structure of the algorithm.

One key aspect of cardiovascular assessment is the motion of the arterial wall. Cinthio et al. [1] highlight the importance of this motion and propose a comprehensive mechanical framework that includes parameters such as blood pressure, variation in arterial diameter, and arterial stiffness. Reliable cardiovascular monitoring also depends on accurate measurement practices and consideration of physiological differences. For instance, Siaron et al. [5] showed that blood pressure readings vary depending on the measurement site, such as the arm versus the wrist. Similarly, Loh et al. [2] found that characteristics like age, sex, and hypertension influence the size of the radial artery.

In recent years, new methods that may allow continuous monitoring of cardiovascular parameters have been developed [3]. Zhou et al. [8] demonstrated the clinical potential of a wearable ultrasound device capable of non-invasive, continuous blood pressure monitoring. Wang et al. [7] further explored this area by combining brightness-mode (B-mode) ultrasound with color Doppler imaging to measure arterial pressure.

To estimate radial blood pressure from ultrasound data, it is crucial to analyze both the cross-sectional area of the artery and the blood flow through it. Color Doppler imaging enables visualization of flow rate [4]. We hypothesize that temporal changes in arterial cross-sectional area can be used to detect the pulse rate. We present an algorithm that measures the cross-sectional area of the radial artery from B-mode ultrasound and links its temporal variation to heart rate estimation. The method is a further step towards wearable continuous monitoring of cardiovascular health. It could be adapted to portable or patch-based ultrasound systems for use in ambulatory settings, contributing to truly ubiquitous cardiovascular health sensing.

2 Materials and methods

2.1 Algorithm design

An algorithm to measure the cross-sectional area of a radial artery from ultrasound brightness-mode images was developed using Python (v3.12). The flow chart of the algorithm is illustrated in Figure 1.

The data loader script uses Python libraries `zipfile`, `os` and `pandas`. The data loader script finds all "beats" and "summary" files for each subject from the continuous non-invasive pressure (CNAP) measurements, then extracts the time, heart rate, and events data. The event data includes the start times of each recording, which are used to define the 60-second long recordings. The data was cleaned by removing rows where the heart rate recorded values of "NaN". Next, the script defines the subject number as the key and creates a dictionary for each key with the value being a data frame, including the subject's heart rate data.

The detection script uses several Python packages including `OpenCV` (v4.11), `NumPy` (v2.2.3), `matplotlib` (v3.10.0) and `scipy` (v1.15.2). The process for a single ultrasound video feed started by selecting a region of interest (ROI) manually to reduce computation time. Each frame in the video feed was preprocessed by grayscale conversion, median filtering, and contrast improvement with Contrast-Limited Adaptive Histogram Equalization (CLAHE). Then, Sobel edge detection from `scikit-image` (v0.25.2) was used to extract edges and their magnitude in the image. The edge-detected image was profiled from the approximate center. The upper and lower sectors of the artery were profiled, with 40 profile lines per hemisphere (cf. Figure 2a). Each profile is processed to yield an approximate location for the artery wall, defined as the location of the highest derivative (cf. Figure 2b and c). Sudden point movements between frames are damped to reduce detection errors. The points were further processed by filtering for outliers. Finally, the filtered points are used for an initial algebraic fit (TaubinSVD; `circle-fit` (v0.2.1)). This initial fit was given as a starting point for a geometric fit (LM; `circle-fit` (v0.2.1)). This final fit returns the location of the center, the radius and the error for the fit which are all saved to a csv file.

For post-processing, the measurements are converted from pixels to millimeters using a manually measured conversion rate (1 pixel = 0.04 mm). After this, a Savitzky-Golay moving average filter with a window size of 6 and polynomial order 0 was applied for smoothing. A 4^{th}-order Butterworth band pass filter is then applied with cut-off frequencies of 0.5 Hz and 4.0 Hz to isolate relevant signal

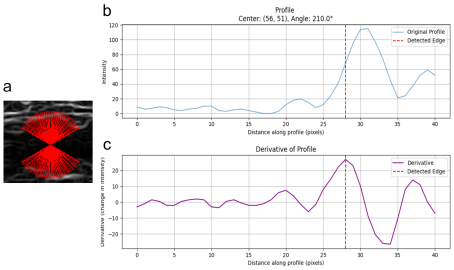

Figure 2: A representative example of (a) the 40 profile lines (—) used to find the approximate location of the artery wall; (b) an associated intensity profile plot of a single line of a single frame; and (c) the derivative thereof. The location of the detected edge (- -), which is the point where intensity increases the quickest along the profile line, is also shown.

components. Finally, the pulse rate is estimated by identifying the highest frequency component in the signal using the FFT function of MATLAB® (The MathWorks, Inc., Natick, MA, USA).

2.2 Algorithm verification

Verification was performed by generating a synthetic 60 seconds long video simulating arterial expansion and contraction over time using `openCV` and `numpy`. The simulated artery had a fixed pulse rate of 50 beats per minute (BPM). The video also provided the time series of the true area of the simulated artery. To evaluate the performance of the algorithm under more challenging conditions, the background intensity could be adjusted.

2.3 Algorithm validation

To generate data to validate the algorithm, ultrasound imaging was performed on the left radial artery of the wrist, as demonstrated in Figure 3. Measurements were acquired using an L18–5 linear probe of a HOLOGIC® SuperSonic™ MACH 30 ultrasound imaging platform (Hologic, Inc., Marlborough, MA, USA). The position of the probe was transverse to the radial artery at the level of the proximal palmar fold. The probe was held in place using a custom-made probe holder to minimize movement and ultrasound coupling gel was spread on the transducer. All probe placements and ultrasound acquisitions were performed by a single operator to ensure measurement consistency.

Ultrasound imaging was performed in brightness mode with a penetration depth of 15 mm relative to the probe surface. During acquisition, the mechanical index was 0.6 with thermal index of 0.0. A 60 second video recording was captured for each subject.

To enable comparison and validation of the algorithm performance, a CNAP® Monitor 500 HD V1.4 device (CNSystems Medizintechnik GmbH, Graz, Austria) was operated in parallel with ultrasound acquisition. The CNAP device was attached to the proximal phalanges of the index and middle fingers of the right hand (cf. Figure 3). A single operator handled CNAP calibration and data setup per subject.

To synchronize the CNAP and ultrasound recordings, the operators of both devices initiated data collection by simultaneously pressing their respective start buttons. Data was collected from six subjects for this study.

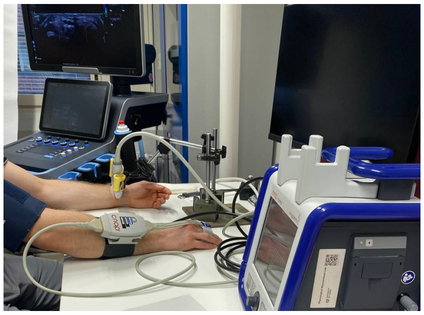

Figure 3: Setup used in the validation experiments. The ultrasound probe was oriented to the radial artery of the left wrist by a custom made probe holder. The CNAP device was attached to the index and middle fingers of the right hand.

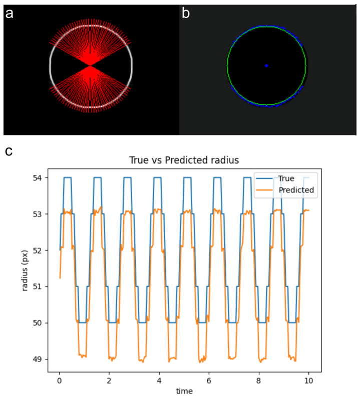

Figure 4: A representative measurement from the simulated video showing (a) the Sobel edge detected image with overlaid profile lines; (b) the found edge points and fitted circle; and (c) a 10-second segment of the measured radius versus the true radius over time.

To validate the accuracy of the algorithm, the mean artery radius and heart rate measured by the algorithm to control values. For the control values of the mean artery radius, a circle was fitted on three manually selected points. For each subject, this was repeated on five equally spaced frames and then the mean of these measurements was calculated. In addition to this, the depth of the artery center from the surface of the tissue was calculated by manually measuring the mean distance of the centers previously mentioned circle fits to the surface of the tissue.

3 Results and discussion

The simulation video had a pixel value difference of 30 between the background and the artery. The algorithm maintained some accuracy even when the pixel difference was lowered to 3, providing an error percentage of 2.65% even for faint edges. A representative result is shown in Figure 4. The detected BPM matched the true

Table 1: Summary of the algorithm measured mean artery radius for the 6 subjects compared to manual control measurements and the distances of the algorithm-based artery centers to the tissue surface.

	Algorithm	Control	Error	Distance to surface
Subject 1	1.42 mm	1.30 mm	9.10%	5.04 mm
Subject 2	1.01 mm	0.95 mm	6.33%	3.72 mm
Subject 3	1.29 mm	1.27 mm	1.31%	5.59 mm
Subject 4	1.56 mm	1.45 mm	7.81%	3.98 mm
Subject 5	0.89 mm	0.96 mm	6.92%	4.58 mm
Subject 6	1.35 mm	1.34 mm	0.92%	4.00 mm
Simulation	51.11 px	52.06 px	1.83%	

Table 2: Summary of the algorithm measured pulse rate in beats per minute (BPM) and corresponding standard deviation for the 6 subjects compared to the control.

		Algorithm	Control
Verification environment		50.0 ± 0.0 BPM	50.0 ± 0.0 BPM
Ultrasound analysis	S1	56.7 ± 1.0 BPM	54.7 ± 0.5 BPM
	S2	55.0 ± 3.0 BPM	54.5 ± 0.8 BPM
	S3	64.5 ± 2.8 BPM	65.1 ± 1.7 BPM
	S4	63.0 ± 3.4 BPM	61.5 ± 0.2 BPM
	S5	61.1 ± 9.6 BPM	68.5 ± 0.6 BPM
	S6	54.4 ± 9.3 BPM	62.4 ± 4.1 BPM

BPM well for 60-second videos, but for shorter 15-second clips the estimated BPM was 48 while the true remained at 50 BPM.

The control values, algorithm-measured artery radius and their error percentages, are shown in Table 1. The error between the control artery diameters and algorithm-measured diameters varies between different subjects. For example, for subject 6, the calculated error is comparatively lower (0.92%) than for subject 1 (9.10%). Also, variation can be seen in the artery center distances to the surface between the different subjects.

Table 2 shows the algorithm-measured heart rate for each subject, the corresponding control heart rate, which was estimated using 20-second windows with 5-second moving steps across the entire duration of the experiment for each participant. Again, we observe noticeable variance in the heart rate accuracy between the different subjects. The deviation of heart rate estimation for subject 5 and 6 is higher than for the rest of the participants. Figure 5 illustrates the same result across all participants, showing how pulse rate estimates compare to the control data.

The small sample size (N=6) restricts the ability to draw general conclusions and increases the risk of overfitting or underestimating variability under real world conditions. The shape of the radial artery was assumed to be a perfect circle, which is a simplification. In addition, data quality was a concern. Ultrasound imaging is inherently noisy due to speckle artifacts. Furthermore, movements of the hand during video acquisition negatively affected the accuracy of the measurement.

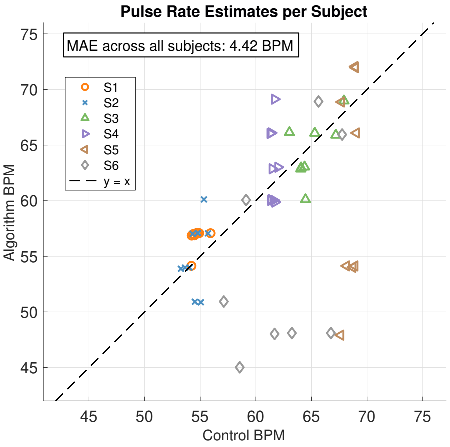

Figure 5: Pulse rate estimates compared to reference across all subjects.

4 Conclusions

Towards the continuous wearable measurement of cardiovascular health, we presented an algorithm to estimate the heart rate and arterial radius of ultrasound videos using image processing techniques. The resulting mean BPM error of 1.81% (std: 1.12%) and mean radius error of 5.40% (std: 3.15%) indicate that the system achieves moderate accuracy. These results are acceptable, but not highly accurate, especially for radius measurements. There is considerable room for improvement before the method can be considered reliable for clinical or even consistent research use.

These limitations point to several key areas for future improvement. A basis for further research would be a more stable measurement setup that eliminates all hand movement. The sample size should also be larger and individual differences should be noted. Improving speckle detection and motion tracking could help to reduce error propagation during analysis. Exploring more flexible geometric models, such as elliptical or deformable shapes, could improve artery shape fitting. Additionally, incorporating probe motion compensation would help maintain tracking robustness. Access to raw ultrasound data, rather than compressed video, would reduce the dependence on pixel-level segmentation. Further development should also aim for real-time processing and minimizing manual intervention, including automated ROI selection and signal quality assessment. In addition, integrating blood flow analysis could allow the estimation of blood pressure from changes in artery diameter, potentially expanding the utility of the system.

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