Estimation of Arterial Pulse Wave Velocity from Doppler Radar Measurements: a Feasibility Study

Rakesh Vasireddy, Josef Goette, Marcel Jacomet, and Andreas Vogt

***Abstract*— Pulse wave velocity has emerged as important diagnostic parameter due to its association with various cardio-vascular disorders, such as hypertension, vascular aging, and atherosclerosis. Long-term monitoring of pulse wave velocity can be beneficial in carrying out accurate diagnosis of the underlying conditions or even for an early prediction of cardio-vascular diseases. Doppler radar has emerged as a promising technology for contact-less monitoring and assessment of physiological parameters. In this study, we aimed at: i) as a first step, assessing the feasibility of measuring arterial pulse waves at the femoral region using the Doppler radar technology, and consequently, ii) estimating the pulse transit time between the heart-femoral regions as well as between the carotid-femoral regions using simultaneous Doppler radar measurements. The results of our feasibility study demonstrate that the arterial pulse waves in the femoral region, arising due to cardiac activity, can be estimated using the Doppler radar technology in a contact-less fashion. Furthermore, simultaneous pulse wave measurements at distinct surface locations using this technique can enable contact-less estimation of the pulse transit time and consequently pulse wave velocity.**

I. Introduction

Non-invasive measurement of pulse wave velocity (PWV) has been one of the most sought-after technologies as long term variations in PWV has been demonstrated as a risk factor for, and an early predictor of, vascular aging, hypertension, atherosclerosis, and overall cardio-vascular mortality [1]. PWV in clinical settings is routinely estimated by measuring the resulting pulsatile activity due to the pumping activity of the heart at two distinct locations on the surface of the body. The distance between the two locations is divided by the phase difference of their pulse waveforms to obtain the PWV between the location pair.

Tonometry approaches, such as PulsePen, non-invasively detect the pressure waveform by means of applanation tonometry [2]. Due to their inherent precise positioning requirements, tonometry based measurements are difficult to procure for long-term monitoring of PWV. As an alternative, approaches using skin-mounted mechanotransducers, such as Complior [3], have been introduced. Mechanotransducer approaches capture surface level mechanical deflections in time domain and thereby calculate the phase difference in pulsations at the two measurement locations. Photo-plethysmography (PPG), routinely used for pulse-oxymetric measurements, is yet another skin-mounted technology capable of delivering non-invasive PWV measurements. PPG PWV approaches employ infra-red radiation emitter-detector pairs to track vascular level volumetric changes due to the blood flow and use the phase difference of these changes between the two locations to calculate the PWV [4]. Skin-mounted transducers have less positioning constraints but are problematic when used in long-term over-night measurement settings due to dislocation of transducer montages and discomfort to the wearer.

In contrast to the above-mentioned approaches that need surface level contact with the subject under measurement, camera-based approaches are truly non-invasive and require no physical contact. Jeong et al demonstrated contact-less Pulse Transit Time (PTT) estimation using a high-speed CMOS digital video camera under flickering free lighting conditions [5]. Although contact-free, visible light imaging approaches suffer from environmental lighting dependencies, which greatly influences the accuracy of long-term measurements. Furthermore, performing over-night measurements are challenging due to low ambient lighting conditions. In order to overcome the problem of ambient lighting, infrared imaging approaches to capture surface level arterial pulsations have been proposed. Garbey et al demonstrated contact-less measurement of cardiac pulses based on thermal imaging of the carotid region [6]. Using a similar setup, Chekmenev et al analyzed the pulsatile nature of the blood flow in the temporal artery [7]. Such thermal imaging based measurements at multiple locations could enable PWV estimations independent of ambient lighting conditions. Nevertheless, the cost of the equipment coupled with the high computational efforts involved have limited this technology to research applications.

Doppler radar has emerged as a promising technology for contact-less monitoring and assessment of physiological parameters. Contact-less estimation of respiration, limb movements as well as heart activity using Doppler radar have been demonstrated [8-10]. In this study, we aimed at: i) as a first step, assessing the feasibility of measuring arterial pulse waves at the femoral region using the Doppler radar technology, and consequently, ii) estimating the PTT between the heart-femoral regions as well as between the carotid-femoral regions using simultaneous Doppler radar measurements.

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Figure 1. Relative positions of the volunteer and the Doppler radar prototype for contact-less measurement of arterial pulse waves at the femoral region.

II. Methods

A. Doppler Radar

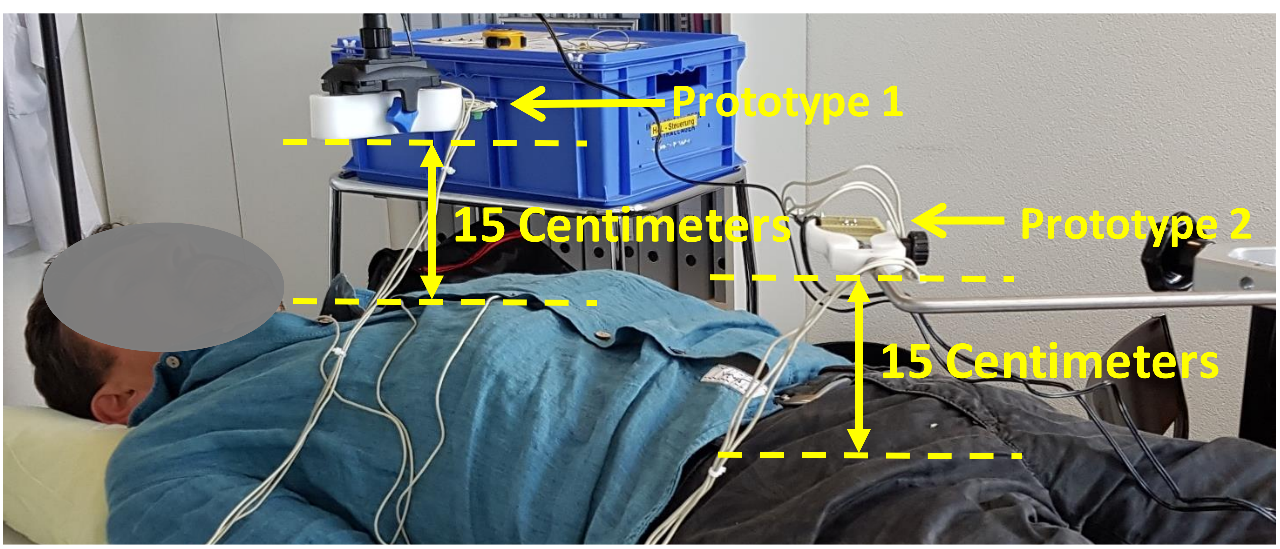
The Doppler radar prototypes used in this study as well as the related signal processing have been described in detail in one of our earlier works [9].

B. Experimental Setup

Upon informed consent, a healthy volunteer (Male, 183 cm, 55 years) with no prior history of cardiovascular complications was recruited for the study. Fig. 1 illustrates the experimental setup used for assessing the feasibility of Doppler derived pulse wave measurements at the femoral region. The prototype was placed directly above the left femoral region at a distance of 15 centimeters. The heart activity of the volunteer (reference measurement) was assessed using a standard pulse plethysmography measurement system (Philips IntelliVue MP50).

Fig. 2 illustrates the experimental setup used for PTT estimations using simultaneous Doppler radar measurements. In order to achieve this, two independently operating Doppler radar prototypes were employed to measure the pulsatile activity at two different locations on the body surface simultaneously. To estimate the PTT between the heart and right femoral regions, prototype 1 was placed directly above the heart region while prototype 2 was placed above the right femoral region. Both prototypes were at a perpendicular distance of 15 centimeters from the surfaces of measurement. Similarly, to estimate the PTT between the left carotid and

Figure 2. Relative positions of the volunteer and the Doppler radar prototypes for the assessment of Pulse Transit Time between the heart and the femoral regions.



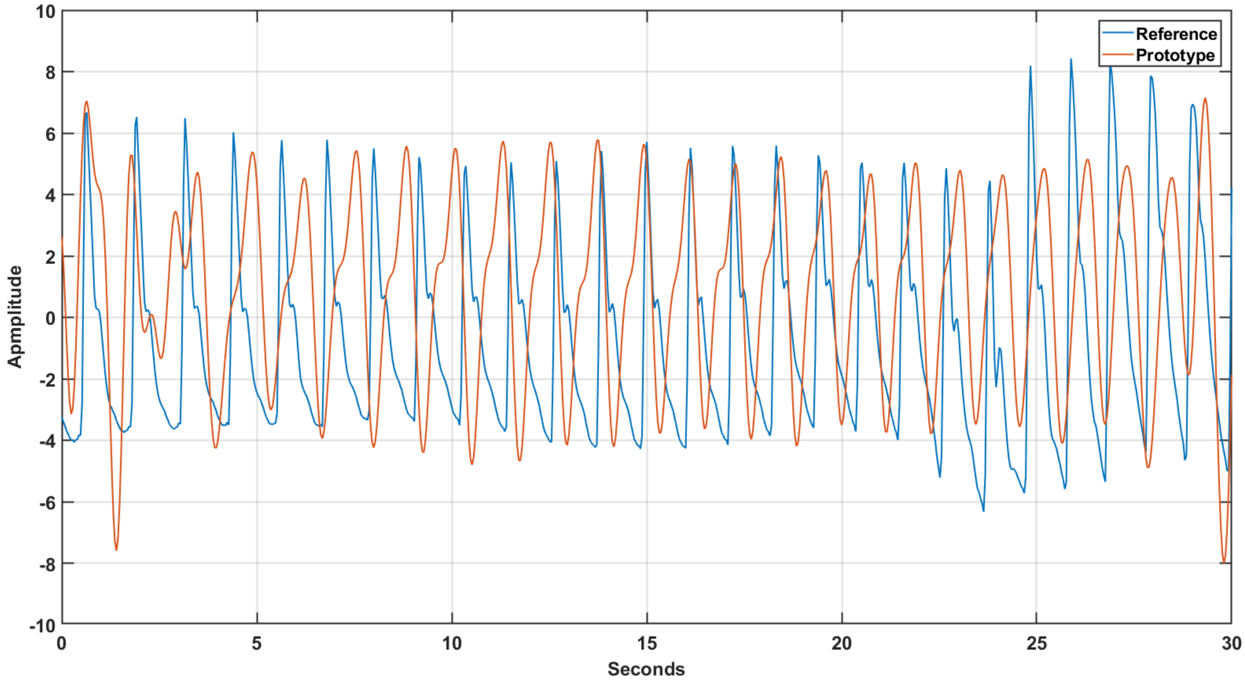
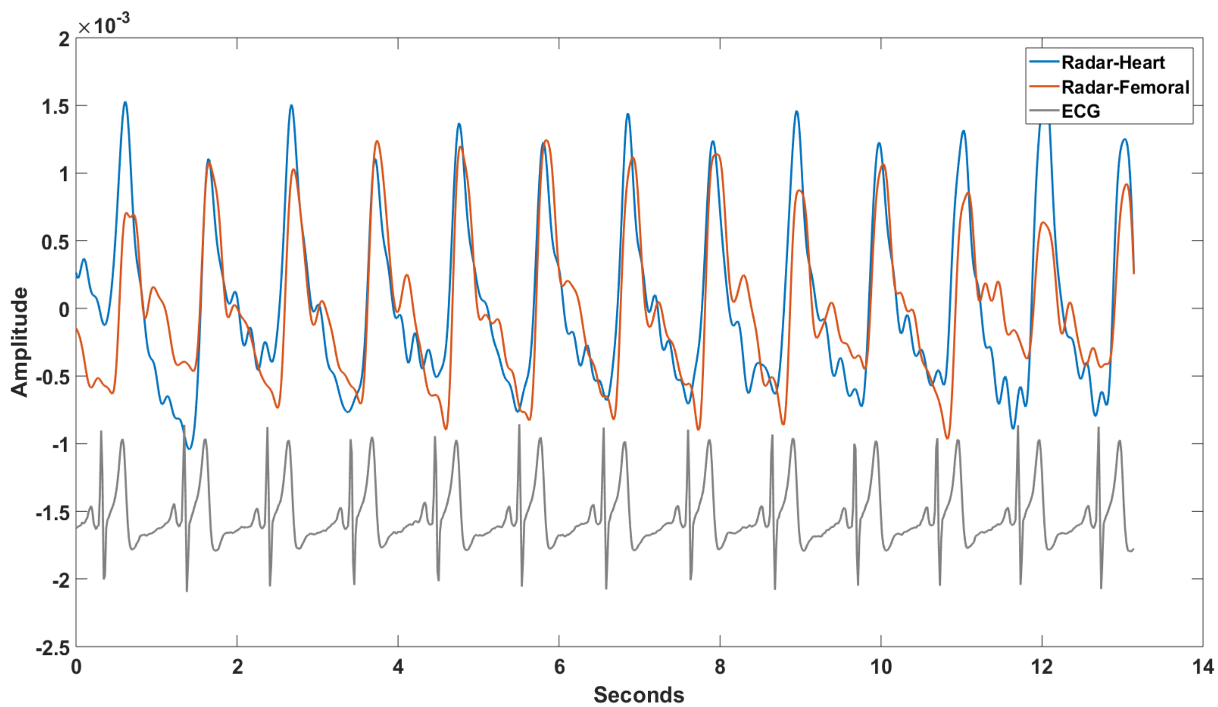


Figure 3. A beat-to-beat comparison between the plethysmographic (Reference) and the prototype measurements from the volunteer during the 30-second breath hold period. The y-axis, 'Amplitude', is a dimensionless reference. The reference heart rate measurement from the period was 51 beats per minute, while the prototype estimated 50 beats per minute.

the right femoral regions, prototype 1 was placed directly above the left carotid region at a perpendicular distance of 15 centimeters, while prototype 2 remained over the right femoral region. The straight-line distances between the regions of heart-femoral as well as between carotid-femoral were measured to be 50 and 70 centimeters, respectively. In addition to the Doppler radar measurements, a standard 3-lead electrocardiogram (ECG) of the volunteer was recorded.

Figure 4. Pulse waves recorded using simultaneous Doppler radar measurements at the heart (blue) and femoral (red) regions with the reference ECG (grey)



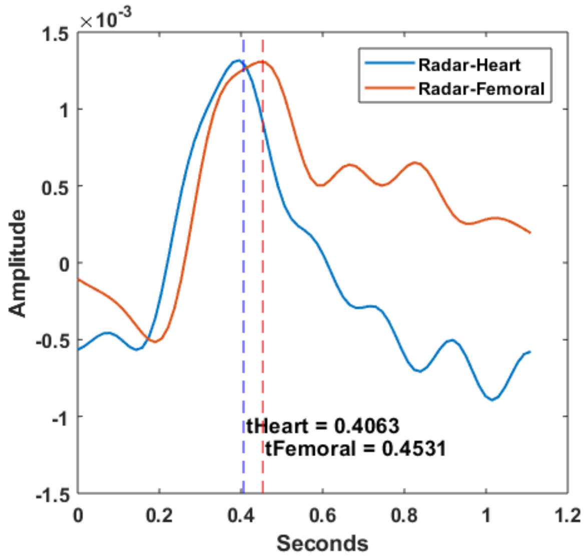


Figure 5. Phase difference between pulse waves recorded at the regions of heart and right femoral artery using simultaneous Doppler radar measurements. Heart Femoral Pulse Transit Time (hfPTT) = tFemoral – tHeart = 47 milli-seconds.

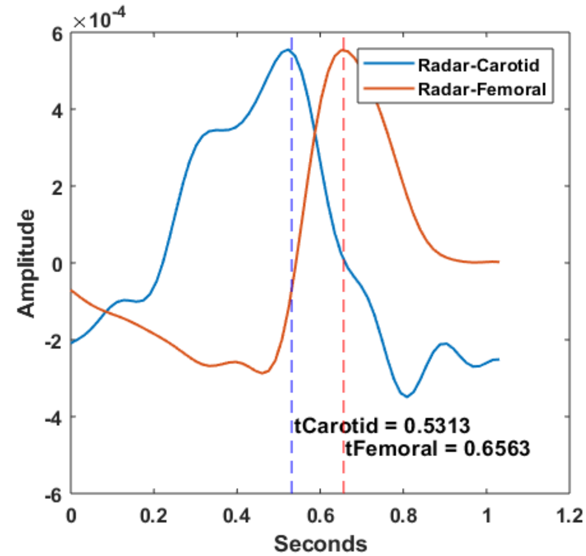


Figure 6. Phase difference between pulse waves recorded at the regions of left carotid and right femoral artery using simultaneous Doppler radar measurements. Carotid Femoral Pulse Transit Time (cfPTT) = tFemoral – tCarotid = 125 milli-seconds.

BioRadio 150 (Great Lakes NeuroTechnologies, Ohio, USA) data acquisition system synchronized all Doppler radar channels as well as the reference ECG signals while performing simultaneous measurements. The volunteer performed a breath hold over a period of 30 seconds to minimize the interference of respiratory motion. The volunteer was clothed at all times during the period of measurements.

III. Results

As a first step, we assessed the feasibility of measuring arterial pulse waves in the femoral region using the Doppler radar technology in a contact-less fashion. Fig.3 illustrates the outcome of these measurements with the pulse plethysmography signal as a reference for the heart activity of the volunteer. During the breath-hold period, the pulse waves derived using Doppler radar measurements are in synchrony with the reference pulse plethysmography signal. Furthermore, the reference heart rate measurement from the period was 51 beats per minute, while the prototype estimated 50 beats per minute.

Upon performing successful Doppler radar measurements in the femoral region as a first step, we attempted carrying out simultaneous measurements at the heart-femoral regions as well as at the carotid-femoral regions. Fig 4. illustrates the outcome of simultaneous Doppler radar measurements at the heart and the right femoral regions, with the ECG signal as the reference for the heart activity of the volunteer. As observed before, both Doppler derived pulse waves, i.e. from the heart as well as the femoral regions, are in synchrony with the reference ECG signal. Furthermore, a distinct phase difference between the pulse waves from the heart and the femoral regions can be observed. Fig. 5 illustrates this phase difference in detail for a single cardiac cycle. The heart-femoral pulse transit time (hfPTT), calculated as the phase difference between the peaks of the pulse waves, is 47 milli-seconds for this cardiac cycle. When divided by the straight-line distance of 50 centimeters between both the regions, this results in an effective PWV of 10.7 meters per second.

Fig. 6, similarly, illustrates the phase difference between the pulse waves from the carotid and the femoral regions for a single cardiac cycle. The carotid-femoral pulse transit time (cfPTT) is 125 milli-seconds for this cardiac cycle, and for a straight-line distance of 70 centimeters between both the regions, this result in an effective PWV of 5.6 meters per second. The PWV estimates derived using the Doppler radar measurements fall within the normal range for healthy adults [11].

A limitation of this feasibility study is the precise positioning of the Doppler radar sensors over the regions of interest. Furthermore, the estimated PWVs could be compared to standard PWV measurements using oscillometeric or tonometric procedures, as used in clinics.

IV. Conclusion

This work showed that the contact-less Doppler radar technology is feasible to estimate the arterial pulse waves in the femoral region, even under covered conditions. Furthermore, simultaneous pulse wave measurements at distinct surface locations using this technique can enable contact-less estimation of the arterial pulse transit time and consequently arterial pulse wave velocity.

In conclusion, the Doppler radar technology could be a promising candidate for contact-less long-term pulse wave velocity measurements.

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