Article

Computation of Vascular Parameters: Implementing Methodology and Performance Analysis

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Abstract: In this paper, the feasibility of automated and accurate in vivo measurements of vascular parameters continuously and non-invasively using ultrasound sensor is presented. Vascular parameters such as pulse wave velocity (PWV), blood pressure (BP), arterial compliance (AC) and stiffness index (SI) are affluent indicators of cardiovascular disorders and needs to be monitored non-invasively and continuously during surgeries and follow-up procedures. Cuff based or invasive catheter techniques are considered as gold standard to measure BP and are fed manually to compute AC and SI which employ imaging algorithms. In this context, a Continuous and Non-Invasive Vascular Stiffness and Arterial Compliance Screener (CaNVAS) is developed to measure said parameters continuously and non-invasively using ultrasound sensor. Acoustic waves of 5 MHz (2.2 – 10 MHz) are driven through target arterial walls, reflected echoes captured, pre-processed and frequency shift is used to calculate PWV. It is observed that PWV measured using CaNVAS varies exponentially with BP values obtained from sphygmomanometer (BPMR-120) and this relationship is used to compute instantaneous values of BP. The proposed device is validated by performing measurements on 250 subjects in pre and post exercise conditions and found to have 95% accuracy and an average of 12.5% coefficient of variation.

Keywords: arterial compliance; stiffness index; pulse wave velocity; blood pressure; acoustic waves

1. Introduction

The World Health Organization (WHO) says cardiovascular diseases (CVD) are the highest cause of mortality globally with around 17.9 million people every year. Hypertension has affected an estimate of 1.13 billion people worldwide, with two-thirds falling in low and middle-income countries. Hypertensive people are more prone to serious medical conditions that significantly increase the risks of brain, heart, kidney, and other diseases. Report says every, 1 in 4 men and 1 in 5 women had hypertension, emerging as a major produce of premature death worldwide. Physiologically, pulse wave velocity (PWV), blood pressure (BP), Arterial Compliance (AC) and

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Stiffness Index (SI) are closely related vascular parameters and play an important role in maintaining blood flow to all vital organs [9,15,39]. Studies have demonstrated a significant correlation between these four parameters and cardiovascular diseases [4,13,21]. Measuring and monitoring these parameters noninvasively and continuously is a main concern for clinicians and there is a need for an automated device, specifically throughout prolonged medical procedures like dialysis and surgeries. First conference of consensus on arterial stiffness (AS) held in June 2000 (Paris, France) summarizes the existing devices for measuring arterial compliance depend on principles like pulse transmit time, arterial pressure pulse and vessel diameter, but are targeted only to measure arterial compliance [28]. Manual measurements of blood pressure based on the gold standard sphygmomanometer demands focused attention and can lead to human errors if operated by an unskilled individual. A noninvasive measurement of AS and AC using traditional oscillometric blood pressure measurement was carried out by Hidehiko et al, [18]. A calibration free Photoplethysmography (PPG) waveform analysis and biometric based technique were used to measure BP [36]. In addition to the above theoretical procedures, there are many patented devices available to monitor BP noninvasively and continuously using cuff-based pressure sensors [7,11,12,35]. Hoctor et al., developed an ultrasonic based method and apparatus to measure BP in a continuous and noninvasive method by capturing images using ultrasound to derive blood pressure values [16]. Recently, Yamil Kuri developed a system and method to determine AC and SI. It was configured to calculate BP based on calculating the blood flow velocity and derived subsequently derived AC and SI [19,38]. Polanczyk A et al., has made hemodynamic studies on three-dimensional reconstruction of the blood vessel and describe its biomechanical properties [30–32].

All these devices monitor PWV, BP, AC and SI parameters individually or collectively either by causing discomfort to subject while continuous measurements or image guided ultrasound modality with complex algorithms. Also, these devices require a large set up for monitoring in intensive clinical environments which makes it more complex for implementation in basic healthcare units at remote areas. Computer and image assisted methods of diagnosis have high accuracy, but repeatability remains a big area to be worked on. Many researchers had discussed carotid stiffness indices which depend on the relation between pressure-diameter of arterial distension from diastolic to systolic phase giving a deep insight on the relation between geometrical parameters of the blood vessel and clinical values [3,14,20,22,24,25,29,35–37,40]. The in-vivo noninvasive technique that employed Young's modulus estimated from the regional stress-strain relationship conveyed depth learning on arterial wall properties [8]. Few studies had worked on the in-vivo Young's modulus measurement of pressure strain relationship on the carotid artery or based on the slope of the stress-strain relationship at end-diastole and end-systole. Young's modulus of the arteries which has a relation between blood pressure and arterial diameter are found to indicate profound variations for different individuals [1,2,5,6,26,34]. Existing Ultrasound imaging has been widely employed in imaging of soft tissues, specifically blood vessels for diagnosing cardiovascular disorders. The movement of the arterial wall can be measured using M-Mode ultrasound method of estimation or using RF signals. These imaging methods have their targets specifically on brachial, femoral, carotid arteries and abdominal aorta [23]. 1D cross correlation method were employed to estimate carotid distention waveform and to visualize its structure [27].

Literature survey indicates that existing modalities employed to find blood pressure and arterial parameters have many impediments. Frequent usage of cuff-based devices may lead to damage of blood vessels and also at any moment an experienced technician is required to detect the Korotkoff sound to evaluate BP. Employing separate modalities like imaging algorithms for finding arterial parameters and invasive catheter methods to detect continuous blood pressure leads to increase in complexity and a potential clinical hazard that stands unavoidable during long term surgical procedure.

Clustering of all these important parameters on a single continuous noninvasive device without complex imaging algorithm is need of the hour and would benefit clinical specialist to successfully carry out prolonged and lifesaving surgeries. In this context, the aim of this research is to develop a device that would measure said parameters continuously and non-invasively using ultrasound

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sensor. This paper further verified the feasibility of automated and accurate in vivo measurements of these parameters using simple and novel methodology which can make CaNVAS a device for potential clinical use in near future.

2. Materials and Methods

This device focuses on deriving blood pressure value from PWV and further AC and SI are computed making it a suitable alternative for existing modalities. Nonionizing ultrasound waves are passed through the blood vessel to get the reflected echoes to evaluate the PWV using Doppler shift. Relation between PWV and BP are established, which helps in automated estimation of BP from PWV. AC and SI are formulated by extracting the derived systolic and diastolic diameter and blood pressure. To validate the entire experimental set up on its working, two checkpoints with artery diameter value as an indicator are programmed to indicate any deviation on device placement in the region of interest. Vessel finder is utilized to trace the artery position or to correct the CaNVAS position whenever needed. CaNVAS is developed to monitor vascular parameters under a single roof in a feasible manner without involving any complex algorithm making it extendable to be employed as a point of care device for CVD patients.

2.1. CaNVAS: System Architecture

The comprehensive CaNVAS architecture is depicted in Fig. 1, showing the modules inherent for measuring the vascular parameters, comprising of a Sensor positioning module contains Illumination using Infrared source, Marking the position of the artery, Embedded ultrasound sensor module contain piezoelectric crystal oscillator of suitable frequency, transmitter unit, receiver unit, pre-processing, module contains acquisition unit, operational amplifier, high pass filter, microprocessor and signal processing module contain extraction of vascular parameters unit, and display module contain manual setting mode and output display unit. Herein it is noted that the term vascular parameters include systolic blood pressure (P_s), diastolic blood pressure (P_d), pulse wave velocity (PWV), which further comprise of peak systolic velocity (V_s) and end diastolic velocity (V_d), arterial compliance (AC), and Stiffness index (SI).

2.1.1. Sensor Positioning Module

A sensor positioning module is provided with artery tracing circuit to support the noninvasive device for marking the correct position of the target artery on the skin surface, whereby illuminating the infrared source of wavelength 620 nm to visualize the target artery. Device embedded ultrasound sensor transmitter comprise of a piezoelectric crystal oscillator and driver circuit, transmits a continuous mode acoustic wave with a frequency F_t, and the receiver module accepts the reflected acoustic wave F_O, which carries distinctive observed frequency against the transmitted frequency, wherein further the shift in frequency between the transmitter module and receiver module is denoted as doppler shift (F_s). The acoustic waves with a pre-determined frequency are transmitted across the blood vessel interface to record the reflected waves from vessel surface with shift in frequency in receiver module. Hence the transmitter module and receiver module are positioned adjacent to each other on the skin surface, along the lines of blood flow targeted towards the receiver module. Crystal oscillator embedded on the device sensor excites the ultrasonic transmitter module to generate the waves at a specific frequency to interact with blood vessel and after absorption the waves are reflected and acquired through the oscillator crystal of the receiver module. Crystal oscillator is controlled by the programmed microprocessor, wherein the excitation of frequency is generated categorically based on the target arterial site. More specifically the transmitting frequency F_t is generated in the range between 1.5 to 3.5 MHz for brachial artery, 4 to 7 MHz for radial artery and 7 to 10 MHz for carotid artery (Ultrasound sensor of 98% accuracy with resonant frequency variation of ± 5 %) to measure the vascular parameters. CaNVAS device was designed for three specific arteries radial, brachial, or carotid, embedding the respective ultrasound sensor and corresponding algorithm to output the acoustic wave of definite frequency on the target site.

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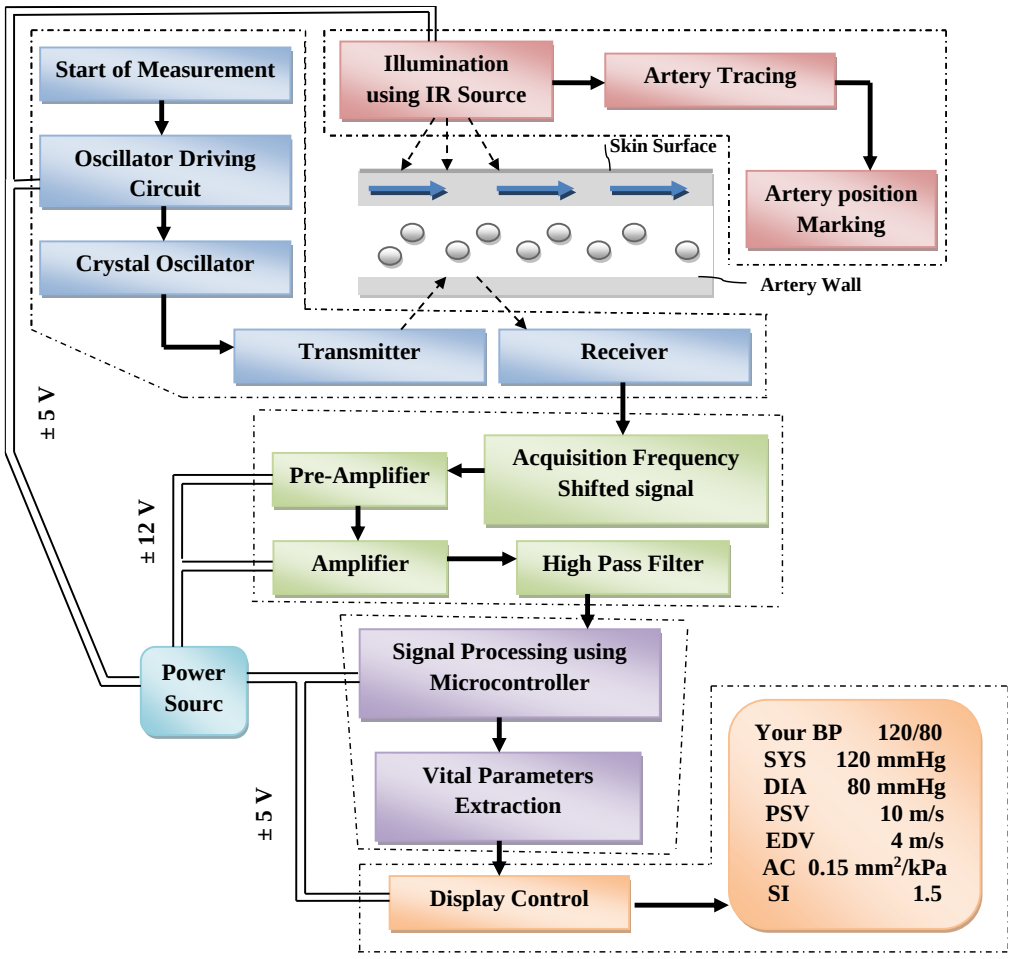

Figure 1. CaNVAS System Architecture.

2.1.2. Pre-Processing Module

Driver circuit is designed in such a way that it guides to transmit the ultrasound acoustic wave at the appropriate frequency towards the target arterial site and the pre-processing module comprises of an operational amplifier and high pass filter, wherein the received acoustic frequency F_O is converted to an electrical signal by a receiver crystal and that electrical signal is amplified by an operational amplifier having a bandwidth of greater than 200 MHz and a slew rate of minimum 4100 Vμs-1. The operational amplifier can amplify the electrical signal by a gain value beyond 25. Further the receiver module is coupled to a high pass network, with a cut-off frequency of 3 MHz to filter the fluctuations on the amplified electrical signal, allowing the sharp amplified electrical signal to a microprocessor. This module is programmed with a structural algorithm to extract vascular parameters from the detected reflected acoustic waves. Two check points, Young's modulus validation to compute the vessel diameter and diameter varying function to correct the device position are included within the algorithm to verify the results obtained simultaneously. Validation unit also incorporated to validate the pressure value from CaNVAS by the operator. A display module continuously provides the data to the user or attender. Herein the data includes the instantaneous systolic blood pressure PS, instantaneous diastolic blood pressure P_d, pulse wave velocity comprises V_s and V_d, arterial compliance, stiffness index of the user, artery position marking and device validation report.

2.1.3. Computation of Vascular Parameters

Unique methodology is carried out in CaNVAS to determine the constants α and β which is fed into the predetermined equation (1) expressing nonlinear relation between the pulse wave velocity and pressure.

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$$P = \alpha V^2 + \beta \qquad (kPa) \tag{1}$$

Doppler shift F_s, which is computed using the received echo signal from the receiver is taken as an input for the equation (2) to derive PWV [37] measure in ms^{-1}.

$$PWV = \frac{C \times F_s}{2\cos\theta \times F_t} \qquad (ms^{-1}) \tag{2}$$

C is the speed of the acoustic wave in the artery, which is 1540 ms^{-1}; F_s is the doppler shift, since the sensors are placed at adjacent, $\cos\theta$ is taken as integrated angle value between $\cos0^{\circ}$ and $\cos30^{\circ}$, which is 0.5. F_t is a transmitter frequency, which is selected in the specific range about 1.5 MHz to 10 MHz based on the target artery, wherein the target arteries are characterized as radial artery, brachial artery, and carotid artery. Instantaneous pulse wave velocity obtained from the subject is used to extract the peak systolic velocity (V_s) and end diastolic velocity (V_d). Minimum and maximum PWV in one cycle duration is determined, of which 70% of the maximum value is taken as V_s and 10% of it is taken as V_d. Reference blood pressure (P_r) parameter from a multitude of 995 random subjects, which includes divergent age group among 21 to 55 (38 ± 17), having various physiological condition like diabetic, high BP and acute cardiac issues were measured by means of an external blood pressure measuring device Diamond Deluxe BPMR-120 and also the reference pulse wave velocity (V_r) from the same random subjects using an initial CaNVAS experimental setup, which is programmed to compute only the PWV (All the subjects included for study are well explained with the procedures and non-objection consent form were collected before recording the data). These reference pressure values (P_r), and pulse wave velocity values are plotted on a graph as depicted in Figure 2 to find the constant values termed as α and β.

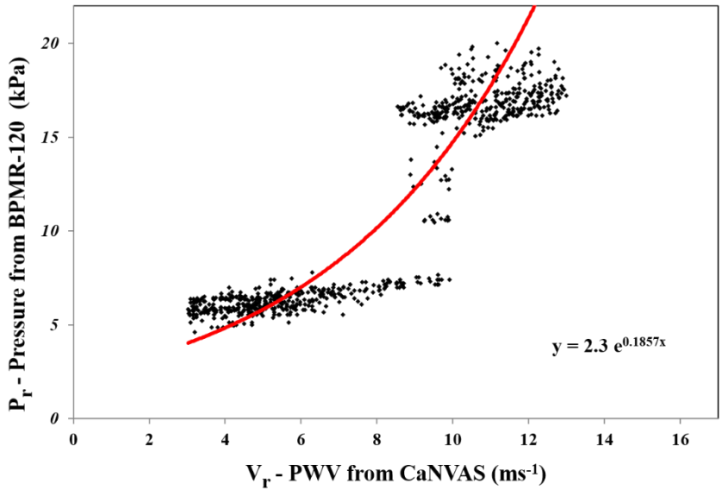

Figure 2. Graph depicts α and β using exponential approximation of Pr and V_r data.

Exponential approximation is employed to analyze the increasing nature of the pressure value to the corresponding increase in velocity value. From the graph it is noted that α constant is the slope of the exponential equation, and the y – intercept is calculated when x is zero and the value is taken as β constant. The α constant 0.1857 kPa and β constant 2.3 kPa, values are observed from the curve and set as a standard constant for the equation (1) to calculate the blood pressure value computed from pulse wave velocity, embedded in noninvasive device CaNVAS. Further the arterial diameter, arterial compliance and stiffness index are computed with an appropriate equation which is embedded in processor to find the vascular parameters of the user using CaNVAS. Herein, the term user or attendant refers to oneself whose vascular or clinical parameters are specifically measured using the noninvasive device. Sequential algorithm carried out in processor as shown in Figure 3 for the computation of vascular parameters.

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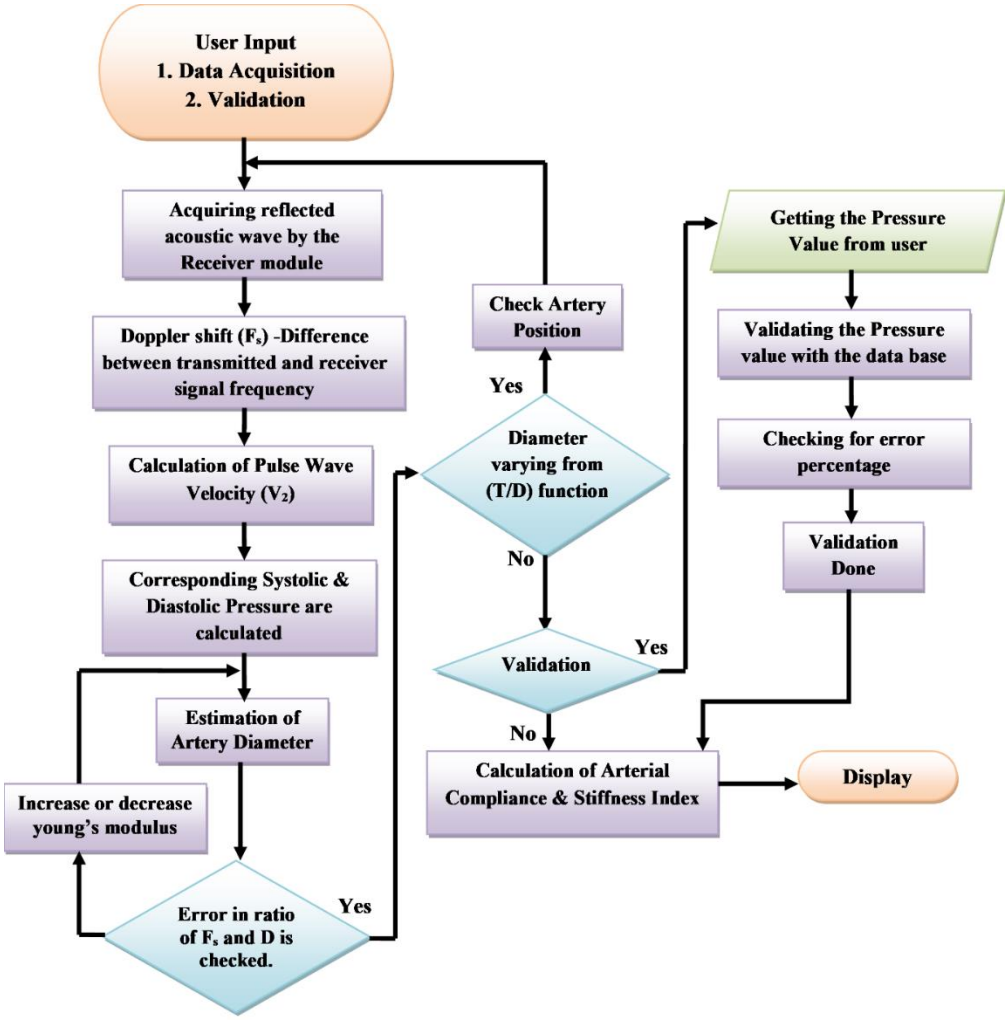

Figure 3. Flowchart representing the process of CaNVAS.

Initially, user inputs are received from the choice of either data acquisition or validation. The pre-processed received echoes are fed into the microprocessor are digitized and the reflected frequency (F_o) is calculated by frequency counter as step1.

$$F_s = F_t - F_o \quad (Hz) \tag{3}$$

In step 2 Doppler shift F_s in kilo hertz (KHz) is calculated using the equation (3), where F_s will be positive since the blood flow towards the receiver. Pulse wave velocity comprises of Peak systolic velocity (V_s) and End diastolic velocity (V_d) are computed in step 3 with the same procedure as carried out in finding the reference velocity values using equation (2). Blood pressure value is derived by applying the velocity values obtained in step 3 and with the derived constants α (0.1857) and β (2.3). Systolic (P_s) and diastolic blood pressure (P_d) in kPa are calculated with the corresponding systolic and diastolic velocity values by the two equations (4) and (5).

$$P_s = \alpha V_s^2 + \beta \quad (kPa) \tag{4}$$

$$P_d = \alpha V_d^2 + \beta \quad (kPa) \tag{5}$$

The processor is programmed with diameter equation to calculate systolic arterial diameter D_s and diastolic arterial diameter D_d in millimeters (mm) of the target artery of the user, using the equations (6) and (7).

$$D_s = \frac{e^{(kPs)_t} E_o}{\rho v_s^2} \quad (mm) \tag{6}$$

$$D_d = \frac{e^{(kPd)_t} E_o}{\rho v_d^2} \quad (mm) \tag{7}$$

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The constants set in the algorithm such as arterial constant (k) is 0.017. Further the artery thickness is set based on the target artery which is 0.25mm for radial, 0.29mm for brachial and 1.5mm for carotid. Constant ϱ is the density of blood, with the value of 1060 kgm^{-3}, P_s, P_d and V_s, V_d correspond to instantaneous systolic and diastolic blood pressure and velocity values obtained in previous steps. Furthermore, elasticity of the artery (E_O) is initially set as 13.33 kPa which will be corrected according to the subject in the approaching steps. Capacity of the artery to compress and extend during systole and diastole in one cycle will reflect its elasticity property and, in the frequency shift obtained from receiver, since the travelling distance of the acquastic waves varies. Ratio of systolic and diastolic diameter is derived and compared with the ratio of maximum frequency shift to minimum frequency shift acquired during one cycle. Differences in value are taken as error and if the error is higher then accordingly the elasticity of the artery E_O is increased or decreased from the set value and step 5 is repeated until the error is minimised. Thus, the terminal value of E_O is appropriated as elasticity value of the user. Another check point is set to correct the system performance. The said non-invasive device inevitably checks the diameter derived from diameter equation against the respective arterial site and it is correlated with the thickness diameter function (T/D) for any deviation beyond 0.3 ± 40% deviation. If the deviation of thickness diameter value is beyond 40%, then it is inferred that the device is wrongly positioned, intimated through display module.

If the user input is received as in step 2, then the device will perform all the previous steps as same as it performed for choice 1 and it performs validation or else its skip's step 8. In the validation part the blood pressure parameter alone is validated with an external device since it is the key parameter in computing arterial diameter, arterial compliance and stiffness index parameters which are sufficient to validate the integrated device. External pressure value is seized as reference blood pressure that are is measured using any gold standard BP apparatus by the user and compared with the values provided by CaNVAS. The device will display the error value if it exceeds ± 0.67 kPa are clinically acceptable. Equation 8 and 9 are employed to derive arterial compliance (AC) in mm^2kPa^{-1} and stiffeness index (SI), where $\mathbf{\Delta P}$ is the difference between systolic and diastolic blood pressure parameter and $\mathbf{\Delta D}$ is the change in systolic and diastolic diameter, calculated in the previous steps using CaNVAS.

$$AC = \frac{\pi(D_s^2 - D_d^2)}{4\Delta P} \quad (mm^2kPa^{-1}) \tag{8}$$

$$SI = \frac{\ln\left(\frac{P_s}{P_d}\right)}{\left(\frac{\Delta D}{D_d}\right)} \tag{9}$$

The subject shall use the noninvasive device CaNVAS with simple operation to retrieve the mentioned vascular parameter details continuously without any time lapse. A display unit, wherein the instantaneous systolic pressure (SYS), the instantaneous diastolic pressure (DIA), Peak systolic velocity (PSV), end diastolic velocity (EDV), arterial compliance (AC) and stiffness index (SI) of the user are displayed continuously and in addition to that the validation status of the device are also displayed. The statistical analysis presented in this paper were carried out using a linear regression model in Microsoft Excel 2016.

3. Results

A total of 300 subjects including healthy individuals and subjects with a history of hypertension, hypotension, treated for cardiovascular disorders and subjects who were undergoing regular renal dialysis in the age group of 21 to 55 years (38 ± 17) with female gender at 65% and male gender at 35% were chosen for the performance analysis of CaNVAS. The subjects involved in the present study includes considerable number of adolescent student and faculty members since the study took place in educational campus. CaNVAS and Diamond Deluxe BPMR-120 were used simultaneously to measure the vascular parameters and the blood pressure respectively of all these subjects. This study was approved by our institute ethics committee and all the subjects were well explained with the experimental procedure and informed consent was obtained before acquisition of data. Typical time taken for one set of reading was less than two minutes. All subjects were exposed to measurement

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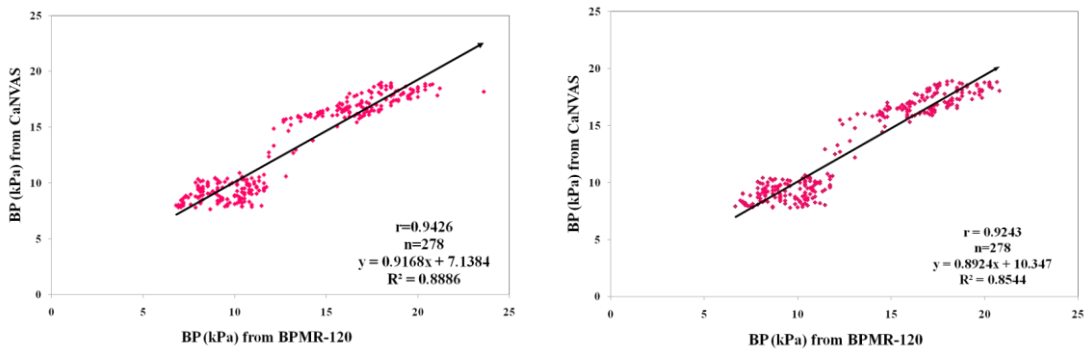
thoroughly. In some cases, the initial setting of the device to the target position consumes few minutes due to the challenge in tracing the artery. BPMR-120 cuff is tied over the brachial artery in such a way that it covers at least 80% of the arm's circumference. CaNVAS is placed over the target (radial) artery with the help of self-evaluation position correcting unit. All subjects were made to sit in a relaxed position with their foot reclining on the floor with the arm supported at the heart level during the assessment. Measurements were repeated for the same subjects after performing some physical exercise (Rapid Steps Climbing), two trials were taken in each condition for the purpose of testing the repeatability of CaNVAS. Blood pressure data obtained using CaNVAS were analyzed with that measured using gold standard Blood pressure device Diamond Deluxe BPMR-120. Of the total 600 data's that inhere two conditions', normal and after exercise, few subject's data were considered outliers due to movement artifacts and powerline interference. Such suspected cases of data having an erratic difference are eliminated and the remaining 556 data are taken for analysis which is 90% of the total.

3.1. Linear Regressiona Analysis

An outline of linear regression analysis of pressure values obtained from two measurement devices during normal and after exercise are shown in Table 1 and Figure 4. Even though the conversion factor (7.501) is used to convert mmHg to kPa unit to match the values obtained from both the device, blood pressure results from CaNVAS is built to have a strong positive correlation with the analogous values accessed from BPMR-120 which are obtained as whole number. Correlation coefficient (r) value of 0.94 and 0.92 are achieved for the pressure values measured during normal and during after exercise respectively. The reason for lesser correlation during after exercise is because of the small-time delay taken for setting the device on the target artery which leads to a sequential measurement rather than simultaneous one while recording data after exercise.

Table 1. Linear regression analysis performed on BP values during two conditions.

Statistical Parameter	BP (kPa) of CaNVAS with BPMR-120	
	Resting Condition	After Exercise
r	0.9426	0.9243
R^2	0.8886	0.8544
Coeff.	0.9168	0.8924
P value	<0.001	<0.001
Intercept	7.1384	10.347



(**a**) (**b**)

Figure 4. Comparison of Blood Pressure (BP) measurements from CaNVAS with those obtained from BPMR-120: (**a**) during resting condition; (**b**) after performing physical exercise.

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To assess the degree of agreement among blood pressure value yielded by CaNVAS and the gold standard device with two conditions, Bland Altman plot with limits of agreement ±2 SD were created as shown in Figure 5. It is noted there is an immense extent of agreement amidst two measurement devices, also the bias value is nearly zero shows reliability of the method carried in CaNVAS to estimate blood pressure from directly measured pulse wave velocity.

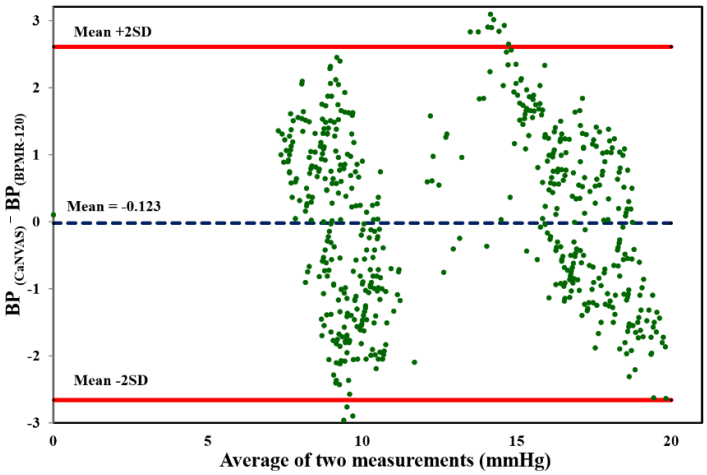

Figure 5. Bland-Altman plot of BP values measured from CaNVAS and BPMR-120 during both resting and after performing physical exercise.

Mean difference between blood pressure values from the two devices were found at -0.123±2.756 demonstrating minimal distort in measurement. The sketch indicates the difference in measurement to be randomly distributed, with 98% of data within the level of agreement.

Correlation matrix is estimated within the vascular parameters for instance Mean Arterial Pressure (MAP), Mean Pulse Wave Velocity (MPWV), Mean Diameter (MD), Arterial Compliance (AC) and Stiffeness Index (SI) calculated using CaNVAS for all ubjects. Correlation coefficients value depicts in Figure 6 has a strong relationship between the parameters of the individuals. Positive correlation is shown for the pairs (i) MAP with MPWV, MD, AC (ii) MPWV with SI, AC, MD (iii) MD with SI, AC which implies slight increase in one value will reflects in another acts as the biomarker for diagnosing vascular abnormalities. There is a strong negative correlation between subject's SI with MAP and AC which indicates an increase in Mean Arterial blood pressure value and Arterial compliance decreases the vascular stiffness that forecast estimation methodology carried in CaNVAS to measure the PWV, BP, AC and SI are trustworthy.

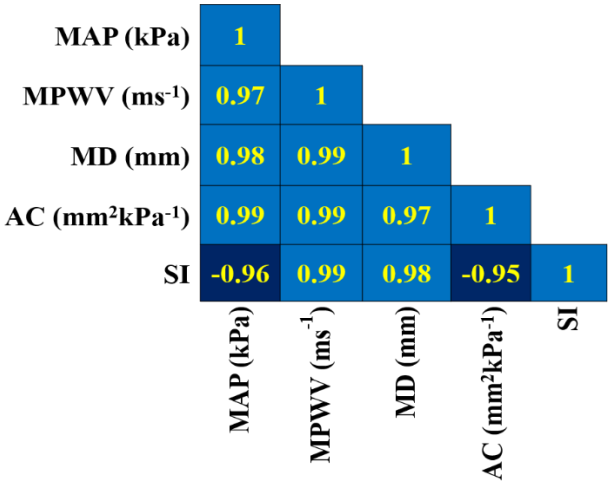

Figure 6. Correlation matrix representing the correlation coefficients calculated between vascular parameters within the subjects.

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3.2. Repeatability Analyisis

Two trials were taken during study to analyse the repeatability of CaNVAS. Frequency of difference in two trials for the BP, PWV, AC and SI values is shown as a graph in Figure 7. The coefficient of variability (repeatability) is figured out as the ratio of standard deviation among the difference between two values obtained from CaNVAS to the average of mean. The coeeficient of repeatability for the above said parameters is tabulated in Table 2. This reveals the intelligence of the gadget to give decisive evaluation of vascular parameters.

Table 2. Coefficient of repeatability for CaNVAS measurements.

Parameters Measured	Coefficient of Repeatability in %
Blood Pressure (kPa)	10.2
Pulse Wave Velocity (ms-1)	11.3
Arterial Compliance (mm2kPa-1)	20.9
Stiffness Index	7.6

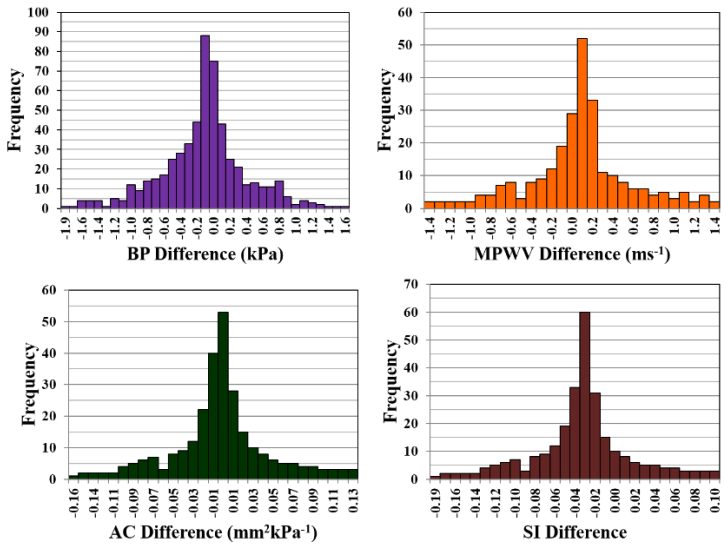

Figure 7. Graph showing the frequency of the error obtained during the measurement of BP, MPWV, AC and SI in two trials.

4. Discussion

A new device and its methodology for evaluating continuous vascular parameters noninvasively named as CaNVAS is presented in this paper. CaNVAS uses an ultrasound technique to measure PWV from the reflected frequency shift signal from artery. This method is promising and is utilized in deriving the BP and further it is also used to estimate AC and SI. Earlier device invented by Drzewiecki et al., (1992) include arterial tonometer to measure the continuous blood pressure noninvasively by identifing the centre of the blood vessel [10] and in their device the deflection area of the artery vessel should be in contact with the sensor surface to get the maximum deflection and it needs specially designed positioning unit. Herein, the proposed device CaNVAS when kept in proximity to the field of blood vessel, records shift in ultrasound frequency thereby overcoming the constraint of involving the entire blood vessel area and the interference angle for observing the corresponding changes. Jeyaraj et al., (2015) has developed a noninvasive device to measure AC and stiffness parameter using ultrasound principle which uses the one-time measurement of BP using external device [17]. Herein, the proposed device CaNVAS has the capability of altogether measurement of instantaneous BP along with AC and SI which makes it superior.

The detailed description of CaNVAS device hardware and its algorithm are explained. Performance of the device were tested with around 300 subjects of different age group ranging between 18-35 (26 ± 9). BP values measured using CaNVAS is verified with the values obtained from sphygmomanometer (BPMR-120) and it has an accuracy of 95%. Reliability of other parameters such as AC and SI measured using CaNVAS are evaluated by self-correlation technique, since it is interrelated to BP i.e., any minimal error in BP measurement will reflect in AC and SI values. AC and SI measured using CaNVAS have a dependence on age factor. Gradual decrease in arterial compliance and increase in stiffness index is observed with increase in age which is alike to the observation made by Jayaraj et al., in the age-related studies of compliance and stiffness factor in their ARTSENS device. Linear regression analysis and Bland-Altman plot were used to authenticate the repeatability of CaNVAS which has an average of 12.5% coefficient of variability which is a comparable result obtained in the previous research.

5. Conclusions

The results obtained certifies that CaNVAS is a promising device for measuring vascular parameters in par with the existing modalities. Compact, affordable, repeatability and user-friendly nature of CaNVAS made it a suitable device for medical use for measuring incessant BP during dialysis procedure, continuous monitoring of health status of the subjects after cardiac surgery etc..,. The limitation of this study is hysteresis behaviour of psychobiological variables during exercise is not considered in this study and will be explored in future work. The subjects involved in the present study includes considerable number of adolescent student and middle age faculty members population since the study took place in educational campus. This is the limitation of our work; the demographic analysis of CaNVAS will be explored in near future.

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