EMPLOYING MICROWAVE RADAR SENSORS, NONCONTACT MONITORING OF RELATIVE CHANGES IN BLOOD PRESSURE

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Abstract

This study attempts to confirm if microwave radar sensors can be used for noncontact monitoring of relative changes in blood pressure. The efficiency of the estimation equation was then verified using data gathered using a noncontact approach while causing fluctuations in blood pressure. First, an equation to estimate blood pressure was developed. Because measurements using microwave radar sensors can measure minute scale motion on the skin surface caused by the pulsation of blood vessels, we thought that the Bramwell-Hill equation, which contains some parameters that directly indicate changes in blood pressure, would be an appropriate reference to construct an estimation equation for the noncontact method. We evaluated a straightforward equation using the pulse transit time (PTT), signal amplitude, and body dimensions as factors to determine relative changes in blood pressure. A cycling task on an ergometer, which causes blood pressure fluctuations due to changes in cardiac output, and a task involving the Valsalva manoeuvre, which causes blood pressure fluctuations due to changes in vascular resistance, were both used to test the accuracy of the equation for estimating changes in blood pressure. The two trials' findings indicated that the proposed equation, which uses microwave radar sensors to measure relative changes in blood pressure, can do so with accuracy. Particularly encouraging outcomes were attained for the variations in blood pressure brought on the variations in heart volume. Although there are still numerous problems, it is possible that this approach may lessen the load placed on patients while advancing the continuous examination of heart function.

Keywords: Continuous Monitor, Blood Pressure, Relative Change, Noncontact Monitoring, Microwave Radar

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1. Introduction

Ischemic heart disease and stroke, which together will account for 17.9 million fatalities in (Pickering, 2002), are the world's two biggest causes of mortality, according to a World Health Organization report. Throughout the past 15 years, these illnesses have continued to be the top causes of mortality worldwide. Also, populations in developed nations are ageing quickly, which is likely to make the problem worse. To assist avoid heart disease, regular cardiovascular system management and monitoring are therefore becoming more and more crucial.

Blood pressure should be measured most often in order to control and prevent heart disease. Invasive monitoring, or measuring blood pressure using a catheter put into an artery, is used in hospitals to assure the quality and accuracy of results. The auscultatory approach employing Korotkoff sounds, the oscillometric method, and the tonometry method are a few more noninvasive techniques that make it simple to monitor blood pressure at home. In home medical care, the electronic sphygmomanometer that is utilised in oscillometric measures has gained popularity. None of these techniques require taking any intrusive measures; instead, they all rely on applying pressure to the upper arm, wrist, or finger with a compression garment known as a manchette or cuff. For individuals with arteriosclerotic vascular disease and arteriosclerotic hypertension, the physical stress brought on by this compression can be extremely taxing and may be followed by several problems, including an increased risk of congestion and undesirable side effects.(Wong et al., 1991) The noises of the pumps or servomotors and the actual pressure to the body may disrupt sleep if nightly blood pressure monitoring is required. Also, a well-known phenomenon known as "white coat hypertension", which refers to the likelihood that the patient's blood pressure would be greater in a hospital setting than at home, frequently takes place. Because blood pressure may be quite sensitive to changes in emotional states, it is advantageous for the patient to be oblivious of when it is being checked. As a result, it is best to check blood pressure covertly, ideally without making physical contact with the patient. Additionally, rather than knowing exact blood pressure numbers, it is crucial to recognise trends in blood pressure variations while administering emergency first aid to individuals who are in a state of shock. This implies that in such circumstances assessments of relative values across time would be acceptable. The same may be stated for cardiovascular disease management and therapy.

In order to assess human vital signs, several noninvasive sensing methods have been developed. A strain gauge and piezoelectric sensors have been used in several noninvasive pulse monitoring investigations.(Heude et al., 1996) A technique for employing a multisensor system to measure a subject's heart rate and breathing has been published by certain research groups.(Jones et al., 2006; Pickering et al., 2005) Innovative vital sign monitoring techniques utilising microwave radar sensors have been put forth recently. These techniques allow for the monitoring of vital signs without the requirement for the monitoring equipment to make physical contact with the subject's body. In several instances, the usefulness of such systems has been illustrated. For instance, microwave radars mounted on ceilings and chairs, respectively, have been used to track changes in autonomic activation and the respiratory rates of patients lying in beds (Jones et al., 2006). These non-contact, non-invasive sensing methods quantify the minute movements of the skin's surface brought on by heart and respiratory activities (Feliciani et al., 2016). Near the skin's surface are veins, capillaries, and other blood vessels, and changes in blood pressure affect how these vessels move. Hence, it is believed that variations in blood pressure cause changes in the motion at the skin's surface, and that this motion conveys crucial information regarding blood pressure. Blood pressure might be monitored without coming into touch with the body if any data regarding variations in blood pressure can be gleaned from the signals obtained by noncontact techniques employing microwave radar sensors. Microwave radar sensors may be transmitted through clothes and bedding and can be used to monitor the movement of a distant item without having to make physical touch with it(Wang & Lin, 2020). As a result, monitoring techniques including microwave radar can be regarded as entirely remote and noncontact. It has also been suggested to use reflected speckle patterns as a noncontact sensing technique, and some promising results have been obtained(Fajkus et al., 2017). But, if there is a shield, such clothing, it cannot be assessed owing to sensing through photonic imaging. So, the accurate detection of variations in blood pressure using microwave radar sensors would be seen as being of great value because such measurements could be made without touch and with no restrictions. A passive cuffless measurement technique has been shown to be effective for taking blood pressure, however there isn't a passive noncontact example in the current paper. Moreover, a series of noncontact unrestricted bio-signal measurements may be obtained using the microwave radar technique that is utilised to monitor micro-vibrations at the skin's surface brought on by heartbeats. Although the component of the motion related to blood pressure is anticipated to be quite small, it is believed that because the motion at the skin's surface is thought to vary with blood pressure, the movement of the skin's surface also contains cardiovascular information related to changes in blood pressure. Moreover, microwave radar sensors that employ this detecting method are legal and safe for use in electrical equipment. As a result, vital signs may be continually monitored; in other words, this sensing approach is suitable for tracking changes in blood pressure relative to baseline.

Given this context, the goal of this work is to establish if relative changes in blood pressure may be measured using microwave radar sensors during noncontact monitoring. To do this, a blood pressure estimation equation was first developed, and its accuracy was then verified using information gathered through noncontact monitoring while causing fluctuations in blood pressure.

2. Thoughts on Theory Related

The force exerted on a blood vessel's wall during the delivery of blood is known as blood pressure.(Uenoyama et al., 2006) According to computer calculations, it is equal to the sum of the cardiac stroke volume and the peripheral vascular resistance.(Suzuki et al., 2013) The process determining blood pressure is really rather complicated since peripheral vascular resistance and cardiac stroke volume are regulated by a variety of methods. As a result, it is usual to use a conceptual mechanical equivalent model to think about the organisation of the cardiovascular system. When thinking about blood pressure and its variation, a number of current conceptual models of the cardiovascular system can be utilised as a reference.

There have been several successful pulse propagation models put forth. The link between pulse wave velocity (PWV), which is defined as the speed of propagation of the pressure wave generated by cardiac systole, and the elastic modulus of the artery wall is described by the Moens-Korteweg equation. The link between the PWV, changes in blood pressure, and changes in arterial volume is described by the Bramwell-Hill equation.(Suzuki et al., 2008)

As blood is expelled from the left ventricle by cardiac systole and the blood pressure in the blood vessel varies, the Bramwell-Hill equation posits that minute changes occur in blood vessel volume and tensile stress. As a result, this equation, where h and r are the blood vessel's wall thickness and radius, respectively, E is the arterial wall's elastic modulus, and is the blood density, yields the following connection between PWV and changes in the blood vessel's volume caused by left ventricular ejection:

$$\mathrm{PWV} = \sqrt{\frac{Eh}{2\rho r}} = \sqrt{\frac{V}{\rho \frac{dV}{dp}}} = \sqrt{\frac{V}{\rho} \cdot \frac{dp}{dV}}$$

where p is the blood pressure, V is the blood vessel's volume elastic modulus, and dV and dp are small variations in each of these variables.

Because it includes a component that directly indicates the change in blood pressure, the Bramwell-Hill equation is suitable for estimating blood pressure. It is reasonable to suppose that the motion at the skin's surface and blood vessel diameter have a proportionate connection. Moreover, the ability to monitor motion at the skin's surface is one of the key features of measurements made using microwave radar sensors. Thus, it is not necessary to establish direct contact in order to use microwave radar sensors to quantify the relative change in blood pressure. It is believed that in some instances, the sensitivity of microwave-based monitoring is subpar when the motion of the artery wall is communicated to the skin because the motion of the skin is controlled by its flexibility. However, in the case of monitoring an artery close to the skin's surface, such as the radial or external carotid artery, it is assumed that the motion of the skin's surface is comparable to the change in the artery's diameter. This could allow for the estimation of blood pressure without physical contact because information equivalent to changes in artery diameter can be obtained by microwave measurement.

Elastic volume modules are used to calculate PWV in the Bramwell-Hill equation as was previously mentioned. This equation for the change dp in blood pressure may be solved to produce:

$$dp = \rho \mathrm{PWV}^2 \frac{1}{V} dV$$

The volume elastic modulus V and its change dV can be converted to the base diameter D of the artery and its change dD as follows to express dp in terms of the base diameter, taking into account previous studies using the cardio-ankle vascular index as an indicator of arterial stiffness typically applied in the diagnosis of arteriosclerosis.

$$dp \approx \rho \mathrm{PWV}^2 \frac{1}{D/2} dD$$

Human blood typically has a density of between 1.043 and 1.060 g/mL(Droitcour & Boric-Lubecke, 2016). It is reasonable to infer that blood density varies between individuals and changes throughout time. According to Bramwell, it may also be inferred that it does not alter quickly over brief periods of time. The density of the blood can thus be considered constant when using blood pressure as the measuring goal.(Droitcour & Boric-Lubecke, 2016) The base diameter D of the artery at the same measurement site does not change throughout the course of the measurement period if the same spot of the same artery is consistently targeted, hence it may be thought of as a constant. As a result, the only non-negligible factors influencing changes in blood pressure in this estimate approach are two. According to the previously discussed conceptual definitions, the change in blood pressure (dp) is a function of two variables, dD (which is influenced by cardiac stroke volume) and PWV (which is influenced by peripheral vascular resistance), as stated by:

$$dp = 2\mathrm{PWV}^2 dD$$

A noncontact approach based on microwaves may be used to determine blood pressure if these two factors could be detected by microwave sensors. As a result, it was thought about whether to collect data from microwave sensors and include it into the calculation.

Initially, it was established how PWV information might be acquired. Two techniques are often used to gather data: electrocardiogram (ECG) readings and finger probe pulse wave recording. The R wave of the ECG may be used to estimate the timing of the left ventricle's ejection, and the position of the oscillation's peak in the pulse waves recorded using the finger probe can be used to determine when the pulse expelled from the left ventricle reaches the finger. The pulse transit time (PTT) is the phase difference between the two timings obtained using these sensing techniques.(Golberg et al., 2018) Based on this widely utilised methodology, two microwave sensors were employed in this work.

Sensor 1 was positioned as close to the heart as feasible, just under a mattress, to collect data on the timing of blood ejection from the left ventricle. As when taking the pulse on the wrist by palpation, sensor 2 was positioned on the left radial styloid process to gather data on the body's perimeter. The PTT was defined as the phase difference between the two output signals obtained from the measurement stations. The peaks corresponding to each pulse in the output signal collected from the microwave sensor were occasionally indistinct because the sent and received microwave radar sensors were not steady. As a result, the cross-correlation between the two sets of data collected from the sensors, with a data length equivalent to a duration of 10 cardiac beats, was used to determine the phase difference for each heart beat.

In addition to the PTT, the journey distance is required to compute PWV. The journey distance, which was determined and used in line with the human body measuring technique, was defined as the distance between the left ventricle and the left radial styloid process. Each subject's arm span S and hand length L were measured (Figure 1(a)), and the trip distance TD was figured out as follows:

$$TD = \frac{1}{2}S - L$$

The PWV was estimated using this information and the PTT as shown in Figure 1(b):

$$dp = 2\mathrm{PWV}^2 dD = 2\left(\frac{TD}{\mathrm{PTT}}\right)^2 dD = 2\left(\frac{\frac{1}{2}S - L}{\mathrm{PTT}}\right)^2 dD$$

3. Methods

3.1. Protocols and the Experimental Environment

As blood pressure is now defined as the product of these two components, two different tests based on the systolic volume and peripheral vascular parameters were performed to confirm the effectiveness of the proposed equation to estimate changes in blood pressure. An ergometer (Aerobike ai-ex, Combi Co., Tokyo) was utilised for the cycling exercise since it is often used in ergonomics and medical research because the physical effort might alter stroke volume. The following drop in blood pressure after the ergometer workout was seen.

The experiment was designed to demonstrate the accuracy of the equation for estimating the change in peripheral vessels by using the Valsalva manoeuvre, which is frequently used in medical research and recognised by the Institute of Electrical and Electronics Engineers (IEEE) as the standard method for evaluating the quality of cuffless blood pressure monitors.

1) In Experiment 1, ten healthy male volunteers between the ages of 21 and 24 (21.70 0.67 years) took part to evaluate how systolic volume affects blood pressure changes. After receiving informed consent and receiving information about the trial, preparations were under way. It was instructed for each healthy volunteer to lie down on a mattress with ECG electrodes, pulse wave, and blood pressure monitor cuffs attached. Two microwave sensors were also fixed into the mattress 12.5 mm from the inside of the left wrist and the surface of the back. After 2 minutes of resting on the mattress, the patient performed the ergometer task for 6 minutes at 150 W and 60 rpm to raise blood pressure. After that, the participant lay back for 15 minutes on the mattress while having his or her blood pressure measured.

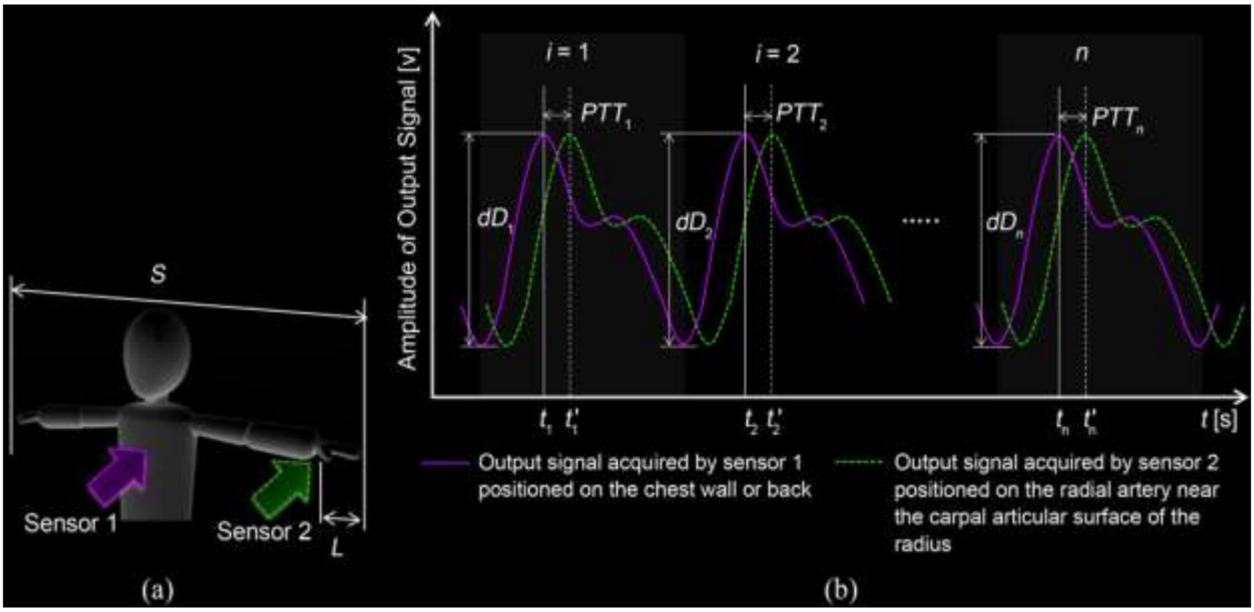


Figure 1: (a) Coordinating points and measurements. (b) image of the recorded waveform and the parameters that give the estimate equation its values.

2) Ten healthy male volunteers ranging in age from 21 to 24 years (21.70 0.82 years) participated in Experiment 2 to observe changes in blood pressure depending on peripheral vessels. Electrodes and cuffs were applied to the subject's body as in the prior experiment after informed consent was acquired and instructions regarding the experiment were delivered. The Valsalva manoeuvre was then carried out after the individual was told to lie on a mattress in the supine position and relax for two minutes. The subject first inhaled deeply and held his breath. Next, the subject bore down and strained his abdominal muscles for approximately 20 seconds. After 20 seconds, the subject released his breath and resumed normal breathing. The subject then rested for approximately 1 minute. During this test, changes in the ECG measurements, pulse waves, and blood pressure were monitored for reference, and the subject was monitored by two microwave radar sensors that had been installed in the mattress.

For the two trials, 10 healthy male students were divided into two groups. However, no statistically significant differences in age (Experiment 1: 21.70 ± 0.67 years, Experiment 2: 21.70 ± 0.82 years, $p = 1$, n.s.) or physical characteristics such as height (Experiment 1: 173.6 ± 5.54 cm, Experiment 2: 169.7 ± 7.69 cm, $p = 0.11$, n.s.) and weight (Experiment 1: 73.53 ± 12.56 kg, Experiment 2: 62.90 ± 8.91 kg, $p = 0.12$, n.s.) were observed.

3.2. Protocols for Data Gathering and Analysis

In general, the two tests employed the same equipment. The subject's precordial ECG was obtained for reference using electrodes (Biotop; NEC Sanei Co., Tokyo) inserted in the V5 position. A finger probe (OLV-3100; Nihon Koden Co., Tokyo) that was positioned on the middle finger of the left hand was also used to measure the pulse wave. Using a manchette on the right arm, blood pressure in Experiment 1 was recorded every minute for 15 minutes (BP-1101; Nippon Colin Co., Tokyo). The blood pressure fluctuates every beat during the Valsalva manoeuvre, thus in Experiment 2, blood pressure was measured beat-to-beat using a finger pressure monitor (Finometer MIDI; Finapres Medical Systems BV, Enschede) (Figure 2(a)). In Experiment 2, the middle finger of the right hand was placed under the tiny cuff of the finger pressure monitor (Figure 2(b)).

To gather cardiac data, two microwave radar sensors (NJR4261J, New Japan Radio Co., Ltd., Tokyo) were employed. The microwave radar sensors have two separate core frequencies to prevent cross talk between them (24.15 and 24.11 GHz). Each sensor additionally has an antenna gain of 10 dBi with a diffusion angle of around 40, a typical output power of 7 mW (maximum: 10 mW), and these additional specifications (TS-01, New Japan Radio Co., Ltd., Tokyo). These two microwave sensors were positioned in the mattress 12.5 mm from the surface of the back (sensor 1) and the inside of the left wrist (sensor 2) in order to record the heartbeat when blood was ejected from the left ventricle and to record the pulsation when the blood reached the radial artery (sensor 2). The two microwave radar sensors' output signals were amplified fifty times by a direct current amplifier (DA-710A; Kyowa Co., Tokyo). An analog-to-digital (A/D) converter (USB-6211; National Instruments Co., Texas) sampled the output signals from the reference devices and the two microwave radar sensors, and then it recorded the data in a computer. The radar outputs were subjected to bandpass filters with a passband of 0.5 - 2.5 Hz after sampling with the A/D converter to lessen interference and noise. These bandpass filters can accommodate pulse rates between 30 and 150 per minute. Following bandpass filtering, parameters from the signal data were gathered to estimate the change in blood pressure. The previously mentioned equation was then used as an input, and the acquired parameters were the outputs.

Excel was used to execute the statistical analysis, and the correlation coefficient value and Bland-Altman analysis were used to evaluate the non-contact approach.

The Kansai University Committee on Human Research examined and approved the study's protocol.

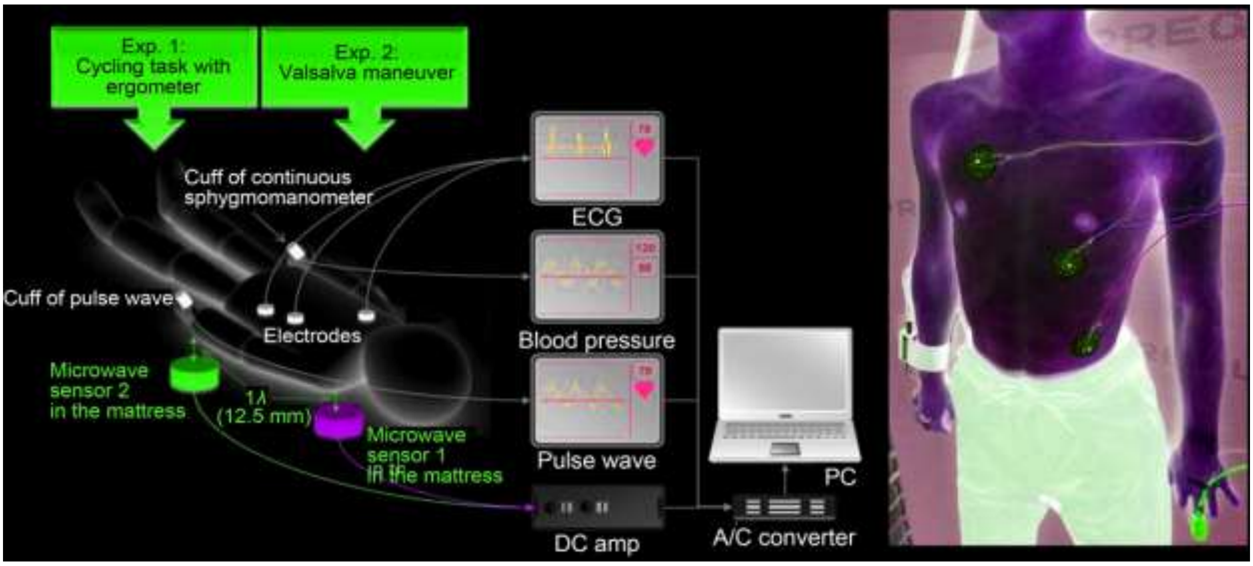
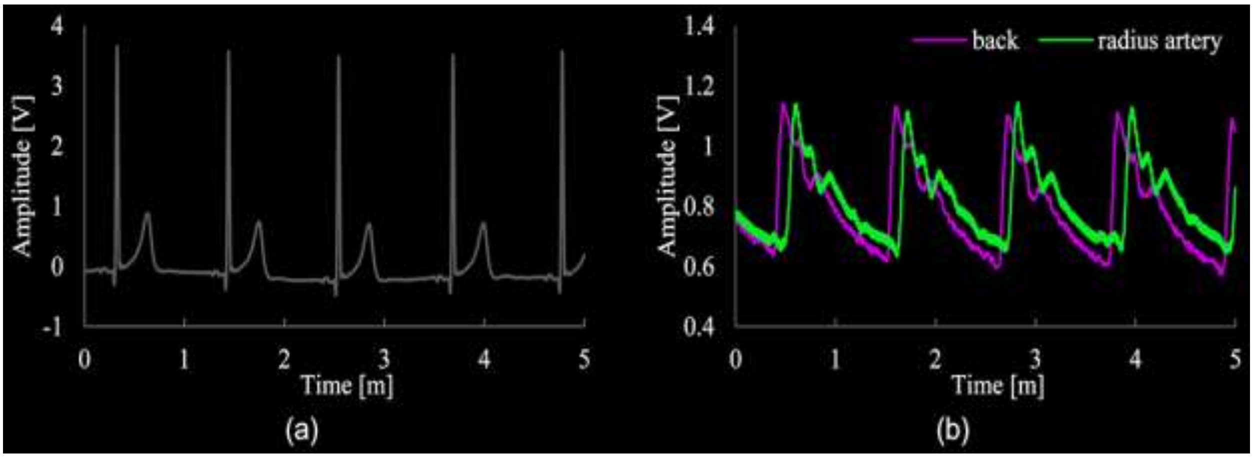


Figure 2: Block diagram of the experiments and the experimental environment. (A) A block schematic showing the experimental environment. (b) A picture of Experiment 2

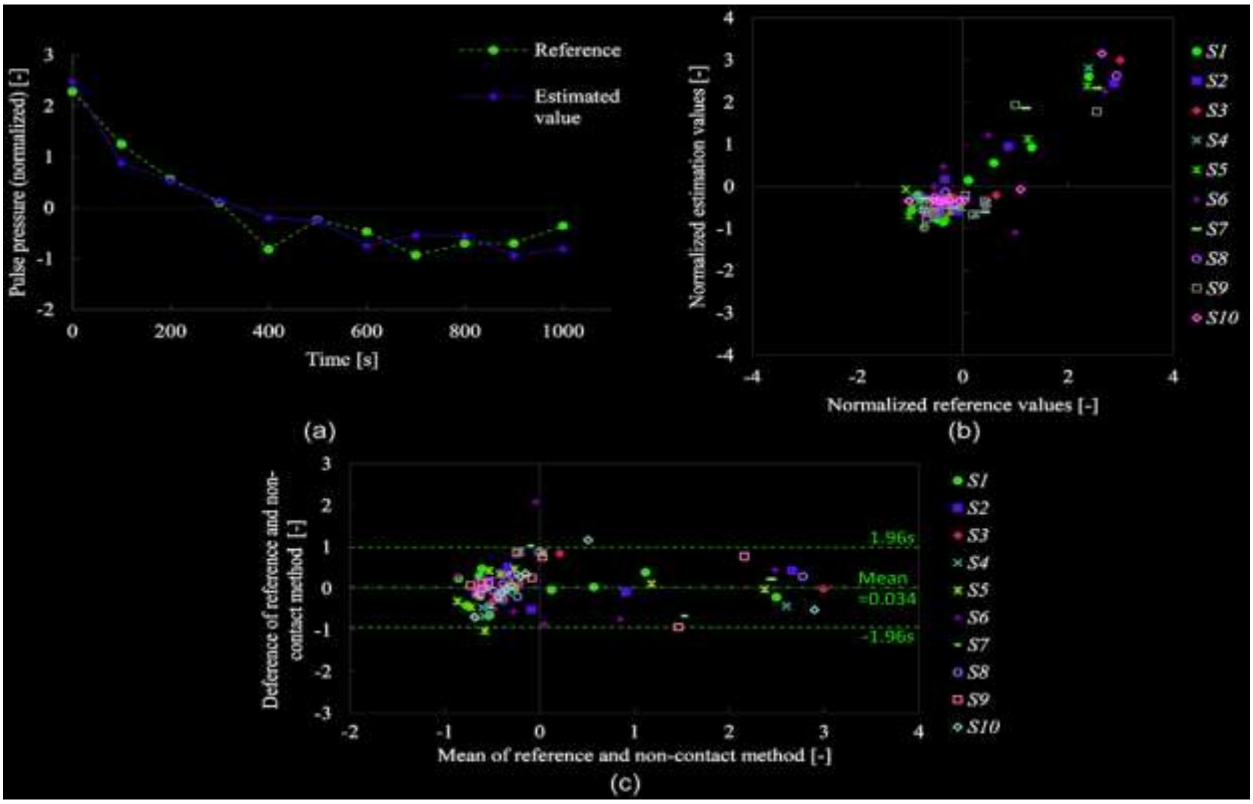
4. Results and Discussions

Due to breathing and movement in certain patients during Experiment 1, a significant overshoot in the collected signal data was mixed in; these data were thus eliminated as abnormal values. In all, 11.82% of the data in Experiment 1 were eliminated as anomalous. In contrast, just 0.77% of the data in Experiment 2 were anomalous. Nevertheless, two of the ten participants did not exhibit the typical changes seen in the prior study when the Valsalva manoeuvre was done, and practically any change in blood pressure was observed. As a result, the analysis was conducted with eight patients since the applied force in the Valsalva manoeuvre was deemed insufficient for these two subjects.



The sample ECG signal for subject S1 during a 5-second period of rest is shown in Figure 3(a). Figure 3(b) displays the signals that correspond to the cardiac oscillation that were simultaneously recorded by the microwave sensors in the mattress for the left wrist and back.

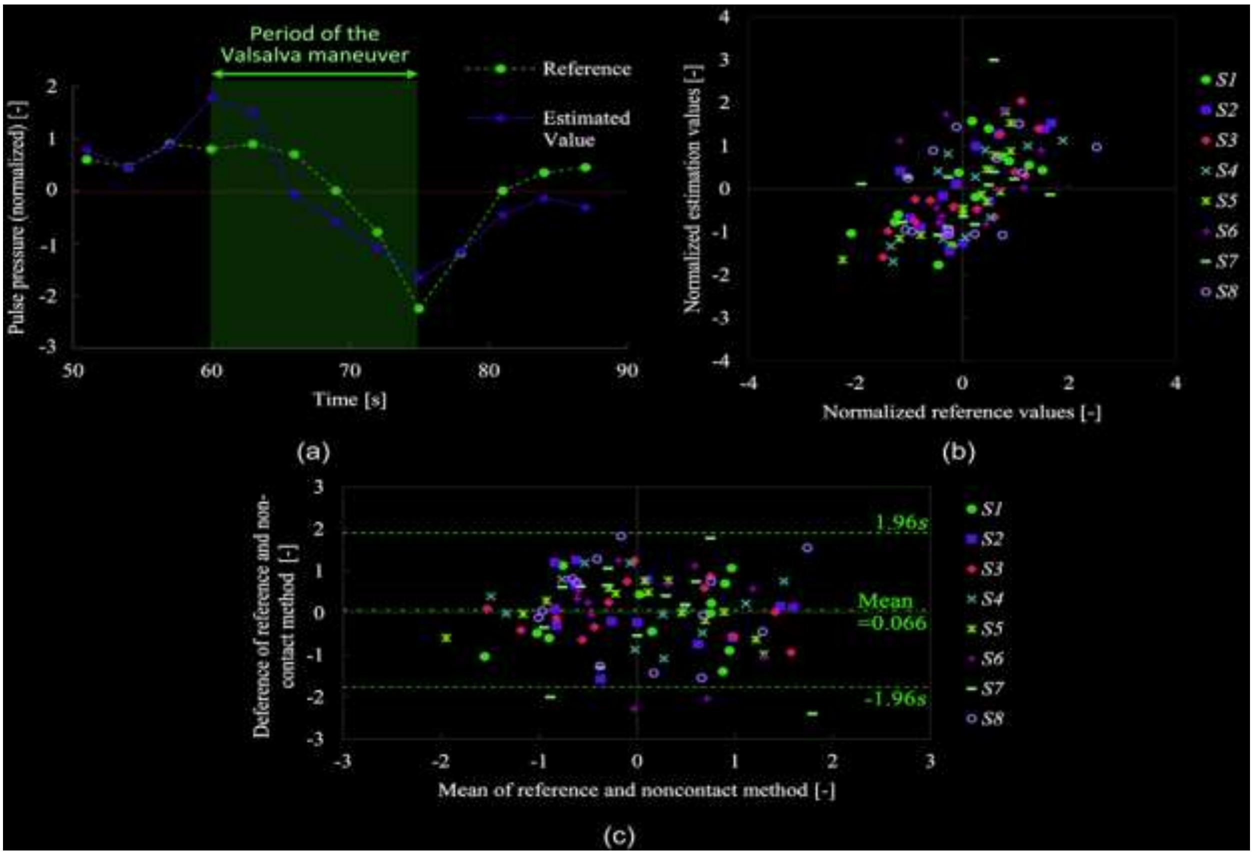
These graphs show that the microwave sensors' output signals showed cyclic oscillations with heart motion that corresponded to the ECG's R-R intervals. Moreover, the PTT might be validated by the phase changes between the waveforms acquired by noncontact measurement from the rear and radius.



The outcomes of the variation in pulse pressure in subject S1 from Experiment 1 are depicted in Figure 4(a). The vertical axis depicts variations in pulse pressure while the horizontal axis reflects time. The dotted line and round marker are changed to reflect the findings of the contact measurement method using a continuous sphygmomanometer to detect pulse pressure. The shift in the diamond-shaped markers connected by the solid line depicts the outcomes of the estimated pulse pressure calculated using the estimation equation based on the information gathered by the microwave sensors as a noncontact measurement. The findings of the reference and estimated values were both standardised in order to compare the degree of change. Figure 4(ahighlighted)'s region illustrates how blood pressure decompression changed over the course of 1000 seconds, from the time of measurement until right after the completion of the ergometer-assisted loading job.

Secondly, it is evident from this figure that after initially rising owing to the physical strain of the ergometer exercise, the blood pressure steadily decreased in a downward trend. All patients showed this pattern, and it took around 10 minutes for the pulse pressure to return to its baseline value. A strong correlation coefficient was confirmed and no significant differences between the two distributions in this subject were identified (r = 0.946, p = 0.500), despite the comparison being limited to fluctuations since all values for both the contact and non-contact measures are normalised. The two values showed a fairly similar trend of change, and every participant verified this tendency.

The two findings measured using the contact technique as a reference and the estimation results based on the noncontact measurement are then compared in Figure 4(b) across all individuals. The results are concentrated in the second quadrant immediately following the physical load and concentrated around 0 at rest due to the peculiarities of this experiment, in which the fall in blood pressure after applying the physical load was seen. Although a strong connection was established, there was no discernible difference between the two outcomes (r = 0.884, p = 0.247). The trend of change predicted by the noncontact approach was taken into consideration to match to the reference since the correlation coefficient, with the exception of one participant, was greater than 0.8. Bland-Altman plots for all patients are displayed in Figure 4(c) (mean = 0.034, upper coefficient limit [UCL] = 0.998, lower coefficient limit [LCL] = 0.930). The plots are concentrated in the UCL and LCL, indicating that there is no difference between the two approaches, despite the fact that they are skewed in the positive direction due to Experiment 1's features.



The findings of Experiment 2 are shown in Figure 5. Figure 5(a) displays the results from the 10 seconds prior to the start of the Valsalva manoeuvre, a total of about 40 seconds during the 15-second Valsalva manoeuvre, and the following 15 seconds returning to baseline because there was no change in pulse pressure at the 1-minute rest interval from the beginning of the experiment.

Because of the Valsalva effect, it was established that the pulse pressure used as the reference for the contact measurement decreased from 60 to 75 seconds during loading. The pulse pressure returned to its baseline value once the load was removed. This variation is also in line with the propensity for pulse pressure variations noted in prior research. Moreover, both the contact and noncontact data supported the same pattern. There was no discernible difference between the two measurement techniques in subject S1, and a rather strong coefficient correlation was established (r = 0.846, p = 0.311). All eight of the participants tested in this trial showed similar alterations, but with minor individual variances.

Similar to Figure 4(b), Figure 5(b) compares the estimate results for each trial and each person using contact and noncontact measures. While being corroborated to some extent by these data (r = 0.575, p = 0.226), the link was not as strong as it was in Experiment 1. The t Bland-Altman plots for all participants are shown in Figure 4(c) (mean = 0.066, UCL = 1.902, LCL = 1.770). Variations in the differences between the two approaches might be validated when compared to the outcomes of Experiment 1. Figure 5 confirms the same tendency as that in Figure 5(b) (c).

Figure 3 shows sample signals that were measured through touch and without contact. (a) A sample ECG signal for comparison. (a) Examples of microwave radar noncontact technique signals (upper part acquired at the back and lower part acquired at the radius).

Figure 4. Experiment 1 results. (a) Sample of the outcomes of the ergometer task in Experiment 1's altered pulse pressure (subject S1). (b) Evaluation of the estimation results based on noncontact measurement and the two values measured using the contact technique as a reference (r = 0.884). (c)

The Bland-Altman plot (mean = 0.034, highest coefficient limit = 10.998, lowest coefficient limit = 0.930) for all individuals.

5. Result Discussion

Because similar characteristics in the cyclic oscillations in the signals acquired by the two methods were observed, it is noteworthy that the same information could be obtained by noncontact sensing when comparing the waveforms acquired by contact measurement as a reference and noncontact measurement in Figure 3. A prior work used the mechanical motions of the skin related to the cardiac cycle as a graphical model approach to signal modelling. In actuality, there is some knowledge about changes in blood pressure associated to skin movements. Also, this noncontact approach employing microwave radar sensors is thought to be adequate for sensing vital signs because several earlier research have also reported on the efficiency of noncontact measurement using microwave radar sensors. There are some instances in earlier reports where measurements were taken from 1 metre or more, suggesting the possibility of extracting estimation parameters remotely from a distance farther than that in the present experiment. However, it is necessary to apply signal processing to remove artefacts and noise.

The estimation results of blood pressure fluctuation obtained by the continuous sphygmomanometer as a reference and the noncontact measurement using the estimation equation suggested in this work were then compared, as shown in Figures 4 and 5, and Figure 6. As a consequence, it was proven, as shown in Figure 4, that the suggested approach could estimate the mechanism by which the pulse pressure decreased following an increase in blood pressure. This finding suggests that when there is a reasonably significant variation brought on by a change in cardiac output, the current estimating approach may corroborate the change in pulse pressure. This blatantly implies that at the very least, the blood pressure reduction may be predicted.

On the other hand, while the accuracy of Experiment 2's Valsalva effect-induced fluctuation, or the fluctuation in pulse pressure brought on by the change in vascular resistance, was somewhat validated, it was still less accurate than Experiment 1. The amount of stress in Experiment 2 and the vascular resistance response to this load, the participants' individual traits, the precision of the sensing, and issues with the estimate equation are a few potential explanations.

It is conceivable that noise or artefacts will impair the signal obtained utilising the noncontact technique. Nonetheless, it is doubtful that the effects of noise had an impact compared to Experiment 1. In Experiment 1, certain significant overshoots brought on by breathing and movement were actually included, leading to the exclusion of some data due to anomalous values. In Experiment 2, this ratio was 0.77% instead of the typical 11.82%, indicating that noise and artefacts had little to no impact on the data.

Also, the change in blood pressure brought on by the change in cardiac output was significant, but the change brought on by the change in peripheral vascular resistance was very marginal. Consequently, it is reasonable to assume that the outcome was first challenging to see. The mean pulse pressure of all individuals in Experiment 1 was really 59.9 mmHg (59.90 7.67 mmHg) before the task and jumped to 91.4 mmHg (91.40 11.34 mmHg) very away after the task, which implies a rise of around 53.0%. Nevertheless, in Experiment 2, the mean pulse pressure of all individuals was 57.19 mmHg (57.19 12.79 mmHg) at rest before the task, but it was 58.51 mmHg (58.51 14.15 mmHg) under the task load of the Valsalva manoeuvre, which is a very tiny difference (2.29%). As individual differences obviously have a significant impact, a high correlation value and favourable outcomes overall are thought to be challenging to achieve. It is likely that the unambiguous correctness of the estimation could not be validated due to the combination of these reasons.

The changes in the reference pulse pressure caused by the Valsalva technique in two patients were distinct from the typical fluctuations described in other research, despite the fact that all subjects had performed it several times before the experiment. We decided to omit these two patients from the study because we felt that the stress of the Valsalva manoeuvre was not administered to them appropriately. Under this circumstance, it is assumed that the control is weak and that performing the Valsalva manoeuvre is difficult for subjects.

Drug control is utilised in medical studies to validate changes in blood pressure; however, in this work, the verification was carried out utilising the task load of the Valsalva manoeuvre, a noninvasive technique often used in blood pressure research. There is no other way to detect blood vessel hardening but by intrusive touch. Consequently, more research is required to confirm in detail the variations in blood pressure brought on by variations in vascular resistance.

A thorough investigation of an equation for estimating blood pressure was done by (Wang & Lin, 2020). The impact of ageing and illness on the mechanical characteristics of the elastic and viscosity models was theoretically investigated.

They concluded that, as a theoretical model, the viscous effect and elastic characteristics owing to age are not greatly affected. This is still debatable, though, as other disease-related variables are thought to be implicated. As a result, it is assumed that the PTT's estimating method is reliable. In comparison to their study, the estimation equation presented in the current research also makes use of two parameters: one is connected to changes in vascular resistance, and the other is related to heart volume. Moreover, even if the denominator and numerator are different, the order is the same since the PWV square is employed. As a result, the estimating equation suggested in this work is likewise regarded as being reliable.

On the other hand, the PTT and amplitude intensity have a significant impact because of the nature of the current estimation equation. The results of Experiment 2 were, however, less satisfactory than those of Experiment 1, suggesting that there may be a problem with the microwave radar sensor's detection accuracy of the PTT or that the PTT change, which was relatively small in comparison to the change in dD, could not be properly accounted for in the equation.

The patients' physical traits, such as their skin diseases, are another set of variables that might impact accuracy. Although some survey results revealed real impacts, it is important to evaluate how these characteristics would be considered in future predictions.

Figure 5. Experiment 2 results. (a) A sample of the findings from Experiment 2's Valsalva maneuver-induced change in pulse pressure (subject S1). (b) Evaluation of the estimation results based on noncontact measurement and the two outcomes measured using the contact technique as a reference (r = 0.575). (c) Bland-Altman plots for all individuals (mean = 0.066, upper and lower bounds for the coefficients are 1.902 and 1.770, respectively).

6. Conclusion

Although though blood pressure is a helpful and effective vital sign for medical diagnostics, it is one of the hardest vital signs to monitor by noncontact means since several criteria, including the density of the blood and the flexibility of the blood vessels, must be validated with contact. The only vital sign for which good and entirely noncontact monitoring is still difficult is blood pressure.

This study set out to verify the viability of measuring relative changes in blood pressure without physical touch using microwave radar sensors. We studied and looked at a noncontact measuring approach in particular based on Bramwell-Hill modelling to continually monitor relative changes rather than the absolute value of blood pressure. We were able to identify certain flaws that need to be resolved in order for this strategy to be applied in the future, and as a consequence, we were able to validate some of its success. Results in particular showed that it would be able to quantify blood pressure variations brought on by changes in cardiac output. However, it was shown that the accuracy was insufficient, necessitating further research, despite the suggestion that the variations in blood pressure caused by organic components in blood vessels could also be assessed. It is undeniable that there are still numerous obstacles in the way of clinical application, including taking physical attributes into account, increasing accuracy, noise processing, and the estimate equation.

The correlation coefficient between the actual and noncontact readings was validated, hence the current findings may be viewed as a success since the relative variations in blood pressure could be determined using a noncontact sensing approach. This is seen to be very important for clinical diagnostics as well as lessening the strain on patients. Particularly, some illnesses, including hypovolemic shock and cardiogenic shock, manifest variations in blood pressure brought on by variations in cardiac outputs. A diagnostic standard for the diagnosis of blood pressure variations states that the systolic blood pressure must be 30 mmHg or more lower than the baseline blood pressure. As it is anticipated that the current approach will be able to detect at this level, it is regarded to have potential for use in the future.

Because elderly patients typically have many underlying conditions, many nations are dealing with an ageing population and rising postoperative management concerns. In the future, super-aging civilizations may be able to control and diagnose their cardiovascular systems thanks to the proposed strategy.

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