CHAPTER 4

ESTIMATION OF BLOOD PRESSURE USING PULSE TRANSIT TIME

4.1 GENERAL

This chapter presents the methodologies that are usually adopted for the measurement of blood pressure, heart rate and pulse rate and the method presently proposed in this research, their comparison in terms of measured values, correlation of the results between the existing and proposed methods and the special merits. At the beginning, initial studies of blood pressure concept in-terms of measurement, techniques and related research is done and then a measurement method based on Pulse Transit Time (PTT) is proposed for this work. Also estimation of pulse rate from PPG which is more convenient than ECG is proposed. This work estimates these two important parameters of cardiology at one time. Blood pressure (BP) is the function of cardiac output which is the amount of blood volume output per cycle. BP is directly proportional to the rate at which the blood travels in arteries and flow rate is calculated from pulse wave velocity. Pulse transit time is the time interval for the arterial pulse pressure wave to travel from aortic valve where it is ejected from the left ventricle to the peripheral site. To determine the time at which the blood leaves the aortic valve, ECG is used. R peak is used as a marker for the time when the blood leaves the aortic valve. With the increase in blood velocity BP increases which means that blood reaches the peripheral site from the aortic valve in a smaller time which means transit time is less and decrease in BP corresponds to longer PTT (Bazzet and Dfeyer 1922).
4.2 BLOOD PRESSURE MEASUREMENT – AN OVERVIEW

Blood pressure is the measurement of the force applied to the blood vessels during blood circulation which decreases as it moves away from the heart through arteries and capillaries, and towards the heart through veins which represent one of the principal vital signs often measured and the most intensively studied parameter in medical and physiological practice.

For each heartbeat, blood pressure measurement varies between systolic and diastolic pressures. The highest pressure occurs when blood travels through the arterial circulation by the contraction of the heart which is known as the 'systolic' blood pressure (SBP), while 'diastolic' blood pressure (DBP) measurement is taken when the heart relaxes between beats during which the pressure in the arterial circulation falls to its lowest level.

Blood pressure is most commonly measured via a sphygmomanometer which consists of a combination of cuff, inflating bulb with a release valve and a manometer. A manometer is a device which historically uses the height of a column of mercury to reflect the pressure. Sphygmomanometer has been the "gold standard" in noninvasive measurement for over 100 years. Figure 4.1 shows the Von Basch’s Sphygmomanometer.

![Figure 4.1 Von Basch's sphygmomanometer](image)

Figure 4.1 Von Basch's sphygmomanometer
Today blood pressure values are still reported in millimeters of mercury (mmHg), though electronic devices which eliminate the use of mercury. In future, invention of nanotechnology promises a better innovation in medical instrumentation which can optimistically measure health parameters.

![Mercury and aneroid blood pressure gauges](image)

**Figure 4.2 Mercury and aneroid blood pressure gauges**

The blood pressure gauges used since years in the medical field is shown in Figure 4.2, mercury and aneroid blood pressure gauges, out of which mercury pressure gauges are still in use in the hospitals compared to aneroid gauges.

![Digital blood pressure meter](image)

**Figure 4.3 Digital blood pressure meter**
With technological advancement in science a more sophisticated and technically sound instrument has been introduced in the medical industry to measure blood pressure digitally as shown in Figure 4.3.

## 4.3 BLOOD PRESSURE MEASUREMENT TECHNIQUES

Blood pressure measurement techniques are generally classified into two basic methods; namely direct and indirect. Direct techniques or invasive techniques provide continuous and much reliable information about the absolute vascular pressure from probes or transducers inserted directly into blood stream. But the additional information is obtained at the cost of increased disturbance to the patient and complexity of the equipment.

Meanwhile, the indirect methods or non-invasive techniques consist of simple equipment and cause very little discomfort to the patient but intermittent and less informative (Walter et al 1976; Khandpur 2005). However, there is accuracy gap between the invasive and the non-invasive methods and has been narrowing with the increasing computational power available in portable units, which can process signal algorithms in speed of nanosecond.

### 4.3.1 Direct (Invasive) Technique

The operation of direct measurement uses a pressure transducer that is coupled to the vascular system through catheter that is inserted into the blood vessel. The measurement is done to a very high level of accuracy and repeatability and is continuous, resulting in a graph of pressure against time. Therefore the direct technique is used when it is necessary to accurately monitor patients’ vital signs during critical care (Khandpur 2005). But it is uncomfortable to patient and has many complications.
4.3.2 Indirect (Non-Invasive) Technique

The conventional technique of making an indirect measurement of blood pressure is by the use of a cuff over the limb containing the artery. This technique was introduced by Riva-Rocci for the determination of systolic and diastolic pressures (Jeremy 1977). The majority of blood pressure measurements require neither continuous monitoring nor extreme accuracy. Therefore non-invasive techniques are used in most cases, maximizing the patient comfort and safety (Yuan-ting Zhang 2004). Currently available devices for non-invasive measurement are manual devices that use auscultatory techniques, semiautomatic devices which use oscillatory techniques and automatic devices whereas most of these devices use oscillatory techniques (Isik 2006).

4.3.3 Auscultatory Technique

Auscultatory techniques use a stethoscope over Riva-Rocci cuff to observe the sounds made by constriction of the artery which is introduced by a Russian surgeon, Nikolai Korotkoff in 1905. Korotkoff found that there were characteristic sounds at certain points in the inflation and deflation of the cuff. These 'Korotkoff sounds' were caused by the passage of blood through the artery, corresponding to the systolic and diastolic blood pressures. A crucial difference in Korotkoff technique was the use of a stethoscope to listen for the sounds of blood flowing through the artery during inflation and deflation of the cuff. The appearance of the first Korotkoff sound is the systolic pressure value and the diastolic pressure value is fixed by the last Korotkoff sound.

4.3.4 Oscillatory Technique

Most automatic devices and semi-automatic devices base their blood pressure estimations on variations in the pressure of the occluding cuff, as the
cuff is inflated and deflated. Similar to the auscultatory technique, oscillometric also applies an inflated cuff to the arm or wrist. These variations are due to combination of two effects: controlled inflation or deflation of the cuff and the effects of arterial pressure changes under the cuff. Instead of detecting the Korotkoff sounds, a pressure transducer is used to record the cuff pressure oscillation while the cuff is being slowly deflated. Therefore in the oscillometric technique, high environmental noise levels such as those found in a busy clinical or emergency room do not disturb the measurement. However any movement or vibration during the measurement will cause inaccurate readings.

The oscillometric technique operates on the principle that as an occluding cuff deflates from a level above the systolic pressure, the artery walls begin to vibrate or oscillate as the blood flows turbulently through the partially occluded artery and these vibrations will be sensed by the transducer system that monitoring cuff pressure. As the pressure in the cuff further decrease, the oscillations increase to maximum amplitude and then decrease until the cuff is fully deflated and blood flow returns to normal.

The cuff pressure at the point of maximum oscillations usually corresponds to the mean arterial pressure. Most available product is automatic type where instead of manually inflated cuff, the automatic devices taking cuff-pressure measurements while releasing the cuff pressure in a controlled way (Andras Mersich and Jobbagy 2002).

4.3.5 Pulse Transit Time Technique

Blood pressure is a function of cardiac output, which is the amount of blood volume output per cycle. It was noted earlier that an increase in the flow rate of the blood causes the blood pressure to rise. Thus, there exists a linear relationship between the blood pressure value and the rate at which the
blood travels in the arteries. This flow rate can be calculated if the pulse wave velocity is known. Although, the PPG waveform is the technique used to measure blood flow in the arteries, the factor that relates the flow to the blood pressure is the pulse transit time (PTT).

Pulse transit time is the time interval for the arterial pulse pressure wave to travel from the aortic valve where it is ejected from the left ventricle to the peripheral site. This peripheral site can be anywhere along the brachial artery where the pulse can be felt the most. The brachial artery is the major blood vessel of the upper arm, so for this reason it is the artery that gets occluded when measuring blood pressure using the traditional mercury sphygmomanometer (Foo et al 2006; GU-Young Jeong 2005; Lass et al 2004; Meir Nitzan et al 2009; Pitson et al 2000).

4.4 PROPOSED METHODOLOGY

Blood Pressure measurement based on Pulse Transit Time (PTT) approach is chosen for this work. PTT is defined as the time interval between two characteristic points – the R peak of the electrocardiogram (ECG) and the peak of the pulse at finger, ear lobe, or toe. PTT is measured by monitoring ECG and Pulse wave in this study. To determine the time at which the blood leaves the aortic valve an ECG is used. R peak is used as a marker for the time when the blood leaves the aortic valve. With the increase in blood velocity BP increases which means blood reaches the peripheral site from the aortic valve in a smaller time that means transit time is less and decrease in BP corresponds to longer PTT. PPG can be acquired from finger, ear, brachial or toes. PPG is taken from fingertip using biokit and pulse rate is estimated from the peak points of PPG signal.
4.5  **BIOKIT PHYSIOGRAPH**

The Biokit Physiograph System is meant for capturing and analysing bio Signals like ECG, PCG, EEG, EMG and Pulse. The signals captured at 1000 samples/second/channel can be analyzed using the Biokit Physiograph Software. The Physiograph System consists of two Models: Built-in Amplifiers and Non-Amplifier Systems. The Built-in Amplifier systems have built in amplifiers for ECG, PCG, EEG and EMG. Non-Amplifier Systems do not have these amplifiers within the system and have to be connected with appropriate amplifier modules for capturing the signals. A measurement taken in the biokit physiograph has been shown in the Figure 4.4.

![Figure 4.4 Biokit Physiograph – Monitoring Screen](image)

4.6  **ESTIMATION OF BLOOD PRESSURE AND PULSE RATE**

4.6.1  **Prototype Wavelet Used**

The choice of the wavelet function depends on the application. The Haar wavelet algorithm has the advantage of being simple to compute and
easy to understand. The Daubechies algorithm is more complex and has a slightly higher computational overhead. But, the Daubechies wavelet picks up the details that are missed by Haar wavelet algorithm. Daubechies wavelet families are similar in shape to QRS complex and pulse signals and their energy spectrum is concentrated around low frequencies. Studies have reported that Daubechies wavelet is more suitable for ECG signal processing; hence for this work this wavelet is used.

4.6.2 Schematic diagram for blood pressure and pulse rate estimation

The ECG and PPG signals are measured using the biokit at a sampling rate of 1000 samples/second. The frequency response of the ECG signal shows its main concentration in the lower frequency range 2-40 Hz and for PPG it is 0.05-10Hz. After removal of noise using DWT, the peaks of the QRS complex with its high dominating amplitude in the signal is detected.

Figure 4.5 Schematic diagram for blood pressure and pulse rate estimation
From the R peaks of ECG heart rate is estimated using: heart rate = 300/no. of large squares between successive R peaks. Similarly the peak and foot point of the peripheral pulse is detected. From the peaks of the PPG, the pulse rate is estimated using: pulse rate = 300/number of large squares between successive pulse peaks. The normal pulse rate varies within the range 60-120 beats/min. There is a time difference between R peak of ECG and pulse peak of PPG which are simultaneously obtained from the two channel DAQ. The difference in time is considered as PTT. Since PTT is inversely proportional to SBP, PTT is calculated from the R peak to the characteristic peak point of PPG.

4.6.3 Noise Removal

Electrocardiogram (ECG) signal, the electrical interpretation of the cardiac muscle activity, can very easily interfere with different noises while gathering and recording. The most troublesome noise sources are the Electromyogram (EMG) signal, instability of electrode, skin effect, 50 / 60 Hz power line interference and the baseline wandering. Such noises are difficult to be removed using typical filtering procedures.

Wavelet thresholding based de-noising methods deal with wavelet coefficients using a suitable chosen threshold value in advance. The wavelet coefficients at different scales are obtained by taking DWT of the noisy signal. Normally, those wavelet coefficients with smaller magnitudes than the preset threshold are caused by the noise and are replaced by zero, and the others with larger magnitudes than the preset threshold are caused by original signal and preserved (hard-thresholding) or shrunk (the soft-thresholding). Then the denoised signal is reconstructed from the resulting wavelet coefficients. This method is simple and easy to be used in de-noising of the ECG signal. But hard thresholding de-noising method may lead to the oscillation of the reconstructed ECG signal and the soft thresholding de-
noising method may reduce the amplitudes of ECG waveforms, and especially reduce the amplitudes of the R waves. To get better results an improved thresholding de-noising method is used which is between hard and soft thresholding.

In this method ‘DB6’ wavelet is used for processing and the ECG and PPG signals are decomposed into 8 levels and 10 levels respectively as shown in the block diagram in Figure 4.6.

![Block Diagram](image)

**Figure 4.6 Noise Removal Technique**

As a result, approximate coefficients and detailed coefficients are obtained. Then hard and soft thresholding is applied to the detailed coefficients. After then reconstruction of the de-noised signal is done from detailed and approximation coefficients by inverse discrete wavelet transform to get a denoised signal which is then subtracted from appropriate approximation levels to get the baseline corrected signal. A8 and A10 for ECG and PPG signals are used respectively for reconstruction.
4.7 SBP ESTIMATION

PTT is defined as the time interval between the R wave peak of ECG and the peak of PPG in the same cardiac cycle. With sampling rate known, using the difference in index values of the peak onset of the two signals, it is possible to calculate the Pulse transit time. Using the Equation in 4.1, it is clear that BP and PTT are inversely proportional or in other words BP increases with decrease in PTT and vice-versa. The relation between blood pressure and PTT is given in Equation 4.1 (Kalju Meigas et al 2001).

\[
\text{BP} = \frac{1}{\alpha} \left[ \ln \frac{L2d\rho}{(E_0h)} - \ln \text{(PTT)} \right] 
\]

Where, \(E_0\) is Young’s Modulus of arterial wall at zero pressure, \(h\) is the brachial artery wall thickness, \(d\) is inner radius of brachial artery, \(\rho\) is the blood density, \(L\) is distance of heart from fingertip and PTT is the pulse transit time.

We approximate the linear function of PTT and SBP by first order regression analysis in MATLAB and the SBP values are estimated (Zhang et al 2008). The final equation of first order regression is given in Equation 4.2.

\[
\text{SBP} = (-0.6881 \times \text{PTT}) + 210.94
\]

The estimated SBP is compared with the mercury manometer used in the hospital. Table 4.1 shows that the proposed methodology successfully calculated the value of SBP by PTT. From the result, it is found that the relation between BP and PTT is almost linear. But since the approximation of linearity is done only for few people, the accuracy is not very high. The
maximum error between the estimated SBP from PTT and measure SBP from mercury manometer is 2% and minimum error is 5%.

Figure 4.7 Experimental Setup of data acquisition

The experimental setup depicting the instrument and the software used is shown in Figure 4.7.

Table 4.1 Measured and estimated values of heart rate, pulse rate and SBP

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Heart Rate (estimated) bpm</th>
<th>Heart Rate (measured) bpm</th>
<th>Pulse Rate (estimated) bpm</th>
<th>Pulse Rate (measured) bpm</th>
<th>PTT (ms)</th>
<th>SBP (PTT) (estimated)</th>
<th>SBP (mercury manometer) (measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>76</td>
<td>80</td>
<td>75</td>
<td>79</td>
<td>122.12</td>
<td>126.91</td>
<td>123</td>
</tr>
<tr>
<td>Patient 2</td>
<td>67</td>
<td>71</td>
<td>63</td>
<td>71</td>
<td>130.52</td>
<td>121.12</td>
<td>118</td>
</tr>
<tr>
<td>Patient 3</td>
<td>78</td>
<td>79</td>
<td>80</td>
<td>80</td>
<td>79.41</td>
<td>156.29</td>
<td>150</td>
</tr>
<tr>
<td>Patient 4</td>
<td>93</td>
<td>92</td>
<td>95</td>
<td>93</td>
<td>98.02</td>
<td>143.49</td>
<td>139</td>
</tr>
<tr>
<td>Patient 5</td>
<td>94</td>
<td>96</td>
<td>96</td>
<td>95</td>
<td>93.77</td>
<td>146.41</td>
<td>142</td>
</tr>
<tr>
<td>Patient 6</td>
<td>70</td>
<td>71</td>
<td>68</td>
<td>70</td>
<td>116.01</td>
<td>131.21</td>
<td>129</td>
</tr>
<tr>
<td>Patient 7</td>
<td>78</td>
<td>80</td>
<td>75</td>
<td>80</td>
<td>122.41</td>
<td>126.71</td>
<td>123</td>
</tr>
<tr>
<td>Patient 8</td>
<td>96</td>
<td>102</td>
<td>101</td>
<td>104</td>
<td>105.23</td>
<td>138.53</td>
<td>136</td>
</tr>
<tr>
<td>Patient 9</td>
<td>74</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>110.86</td>
<td>134.65</td>
<td>131</td>
</tr>
<tr>
<td>Patient 10</td>
<td>96</td>
<td>100</td>
<td>98</td>
<td>101</td>
<td>100.77</td>
<td>141.60</td>
<td>138</td>
</tr>
</tbody>
</table>
Table 4.1 shows that the proposed methodology successfully estimated heart rate as well as pulse rate of the patients. The estimated heart rate and pulse rate is compared with bed side monitor used in the hospital. From the result it is found that there is good correlation between the estimated and measured values with a minimum error of 2% and maximum error of 5%.

4.8 SIMULATION RESULTS IN MATLAB

4.8.1 Signal Acquisition

The signal acquired from the biokit has been sent to MATLAB and plotted. ECG and PPG signals obtained are presented in Figure 4.8.

![Figure 4.8 ECG and PPG signals](image)

4.8.2 Wavelet Decompostion of ECG Signal

Further the obtained ECG signals have been decomposed to obtain 8 levels using Daubechies wavelets. Figure 4.9 presents the reconstructed approximation and decomposed coefficients of the ECG
4.8.3 Wavelet Decomposition of PPG Signal

The wavelets are purposefully crafted to have specific properties that make them useful for signal processing; here the wavelet decomposition of PPG signal has been presented in Figure 4.10.
4.8.4 Preprocessing of ECG signal and Heart Rate Estimation

In Figure 4.11 the top portion shows the ECG as originally obtained. Middle portion shows the denoised and baseline corrected signal using wavelet based method. Since the R peaks and its position are required for heart rate and PTT estimation, the R peaks are detected using wavelets and the estimated heart rate is presented in bottom of Figure 4.11

![Image of ECG preprocessing and heart rate estimation](image)

**Figure 4.11 Preprocessing of ECG and heart rate estimation**

4.8.5 Preprocessing of PPG signal and Pulse Rate Estimation

In Figure 4.12 the top portion shows the PPG as originally obtained. Middle portion shows the denoised and baseline corrected signal using wavelet based method. Since the pulse peaks and its position are required for pulse rate and PTT estimation, the pulse peaks are detected using wavelets and the estimated pulse rate is presented in bottom of Figure 4.12

![Image of PPG preprocessing and pulse rate estimation](image)
4.8.6  Pulse Transit Time and SBP Estimation

In Figure 4.13 the top portion shows the detected R peaks from ECG and the bottom portion shows the detected pulse peaks from PPG signal. There is a time difference between R peak of ECG and pulse peak of PPG which are simultaneously obtained from the two channel DAQ. The difference in time is considered as PTT. Since PTT and SBP are inversely proportional, using regression analysis SBP is estimated.
RESULT ANALYSIS

The results obtained after the MATLAB signal processing are presented with their respective values of standard measurement and the chart has been plotted for the same. The heart rate and pulse rate values have been plotted in the Figure 4.14.
It is observed that heart rate measured using ECG and pulse rate measured using PPG are more or less the same. Also pulse rate and heart rate measured using the proposed research and the pulse rate and heart rate measured using bed side monitor in the hospital shows good correlation with 2 to 5% variations.

![Figure 4.15 comparison of SBP from automatic BP meter and PTT](image)

**Figure 4.15 comparison of SBP from automatic BP meter and PTT**

The composition between the SBP values obtained from the BP meter and the PTT for ten different subjects has been plotted and presented in Figure 4.15. It is observed that Systolic blood pressure measured using the proposed PTT technique and conventional mercury manometer are nearly equal with a minimum error of 2.21mmHg and maximum error of 6.29 mmHg.
4.10 LAB VIEW IMPLEMENTATION

4.10.1 Pulse Rate Estimation from PPG Signal

PPG signal and ECG signal are acquired simultaneously using a two channel DAQ and sent as input to Lab VIEW. The algorithm used in Lab VIEW detects the index of R peaks and pulse peaks. The RR interval is calculated and heart rate is estimated. Similarly the interval between pulse peaks is calculated and pulse rate is estimated. Using the index values of R peak and pulse peak, PTT has been calculated which is the time difference between the peaks. (Zhang et al 2008) Using the proposed methodology SBP is estimated and is sent out as output by Lab VIEW.

The block diagram in figure 4.16 presents the methodology adopted for pulse rate estimation using Lab VIEW, where the appropriate coefficients have been selected namely A6, D5, D4 and D3. The signal is further processed for multiscale Peak detection, the respective peak locater locates the peaks and using the pulse interval, pulse rate has been estimated by 60/interval between the peaks.

![Figure 4.16 Block Diagram for Pulse Rate Estimation](image-url)
Table 4.2 presents the PTT measured from few of our colleagues. It is found that the SBP estimated from PTT and the same measured from automatic blood pressure apparatus are nearly equal. Also the heart rate estimated from our technique and the same measured from automatic blood pressure apparatus are nearly equal with tolerable error of 2 to 5%.

<table>
<thead>
<tr>
<th>Subject</th>
<th>HEART RATE Estimated (BPM)</th>
<th>HEART RATE Measured (BPM)</th>
<th>PTT (millisecond)</th>
<th>SBP Estimated (PTT) (mmHg)</th>
<th>SBP Measured (auto) (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>81</td>
<td>83</td>
<td>119.32</td>
<td>128.83</td>
<td>124</td>
</tr>
<tr>
<td>Patient 2</td>
<td>103</td>
<td>106</td>
<td>120.82</td>
<td>122.29</td>
<td>117</td>
</tr>
<tr>
<td>Patient 3</td>
<td>101</td>
<td>103</td>
<td>102.81</td>
<td>140.19</td>
<td>135</td>
</tr>
<tr>
<td>Patient 4</td>
<td>76</td>
<td>80</td>
<td>116.10</td>
<td>131.05</td>
<td>124</td>
</tr>
<tr>
<td>Patient 5</td>
<td>104</td>
<td>107</td>
<td>98.62</td>
<td>143.07</td>
<td>140</td>
</tr>
<tr>
<td>Patient 6</td>
<td>101</td>
<td>105</td>
<td>126.96</td>
<td>123.57</td>
<td>117</td>
</tr>
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<td>Patient 7</td>
<td>93</td>
<td>97</td>
<td>86.5</td>
<td>151.41</td>
<td>146</td>
</tr>
<tr>
<td>Patient 8</td>
<td>98</td>
<td>101</td>
<td>93.72</td>
<td>146.52</td>
<td>142</td>
</tr>
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<td>Patient 9</td>
<td>82</td>
<td>86</td>
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<td>102</td>
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<tr>
<td>Patient12</td>
<td>85</td>
<td>87</td>
<td>121.11</td>
<td>127.60</td>
<td>122</td>
</tr>
</tbody>
</table>
4.10.2 SBP Estimation

Figure 4.17 presents the block diagram used for systolic pressure estimation. Here the preprocessed PPG signal is given to multiresolution analysis block and appropriate coefficients are selected for the input to the multiscale peak detection. Pulse rate is estimated by the detected PPG peaks and calculation is done using the interval between two consecutive peaks. Then pulse rate is calculated by 60/interval between the peaks. Heart rate is also calculated for reference by 60/R-R interval. From the detected R peaks of ECG and pulse peaks of PPG, the position of the respective index of R and pulse peak is taken.

Figure 4.17 Block diagram for systolic pressure estimation
Using the difference in index values of the peak onset of ECG and PPG signals, PTT is calculated which is inversely proportional to BP using the proposed methodology.

4.11 SIMULATION RESULTS IN Lab VIEW

4.11.1 Front Panel For Heart Rate Estimation

The front panel of Lab VIEW shown in Figure 4.18 presents the heart rate that has been estimated using ECG signal.

Figure 4.18 Front panel of pulse rate estimation using LabVIEW
4.11.2 Front Panel for pulse rate Estimation

The front panel of Lab VIEW shown in Figure 4.19 presents the pulse rate that has been estimated using PPG signal. Front panel of PTT and SBP estimation using Lab VIEW is presented in Figure 4.20.

Figure 4.19 Front panel of pulse rate estimation using Lab VIEW
4.11.3 Front panel for PTT and SBP Estimation

![Front panel for PTT and SBP Estimation](image)

**Figure 4.20 Front panel of PTT calculation**

### 4.12 CONCLUSION

The heart rate, pulse rate and systolic blood pressure were actually measured for a small group of 10 patients in a private hospital to compare the validity of the algorithm used in this research. It is observed that heart rate measured using ECG and pulse rate measured using PPG are more or less the same. Also the pulse rate and heart rate measured using the technique used in the current research and the pulse and heart rate measured using bed side monitor in the hospital shows good correlation with minimum error of 2% and maximum error of 5%. Moreover it is observed that systolic blood pressure measured using proposed PTT technique and conventional mercury
manometer are nearly equal with a minimum error of 2.21mmHg and maximum error of 6.29mmHg. This algorithm has been tested with few of our colleagues and it was found that the proposed PTT based technique proved to be acceptable when compared with digital BP apparatus used in laboratory. However these results were not used for regression analysis since the mercury manometer and digital BP apparatus are of different standard. Hence our technique in the present research can be confidently applied to measure the above values for patients in hospitals. In future data from more patients with various cardiac problems has to be collected to validate the algorithm.