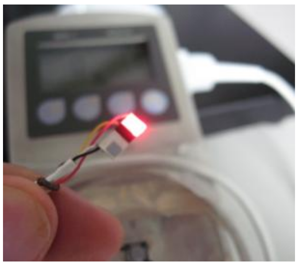
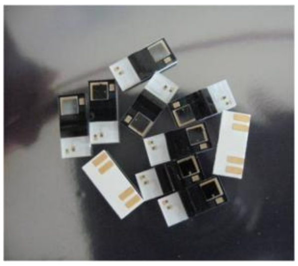
Second Derivative Photoplethysmography Implementation

Photoplethysmography (PPG) provides an estimation of blood flow by measuring the dynamic attenuation of visual or infrared light by the blood volume present in tissue. The contour of the pulsatile component of the PPG signal has been found to include content descriptive of vascular health. PPG pulse signals can be easily obtained from the tissue pads of the ears, fingers and toes where there is a high degree of superficial vasculature. The non-invasive assessment of cardiovascular function by means of the peripheral arterial pulse has gained substantial interest in recent years due to the integration of sensor technology and the ubiquitous application of microprocessors. APMKorea developed DCM01, 02, 03 integrated dual emitters and a detector in single substrate which work reflectively.



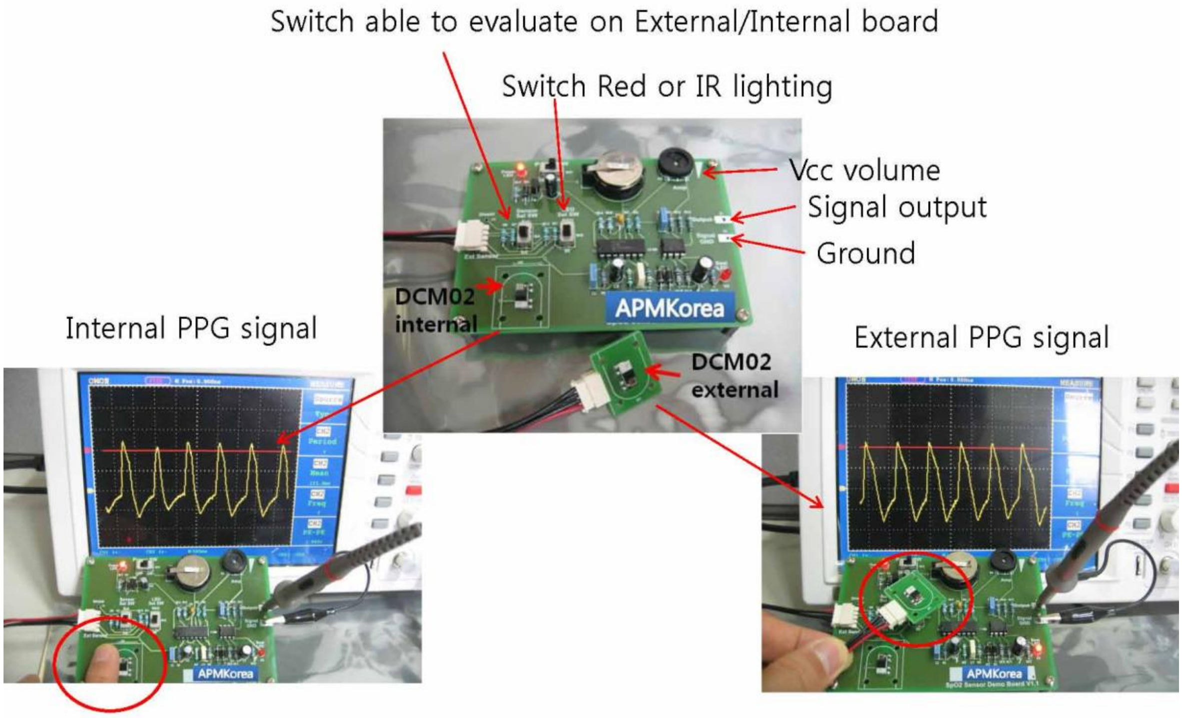
Reflective Sensor

DCM01



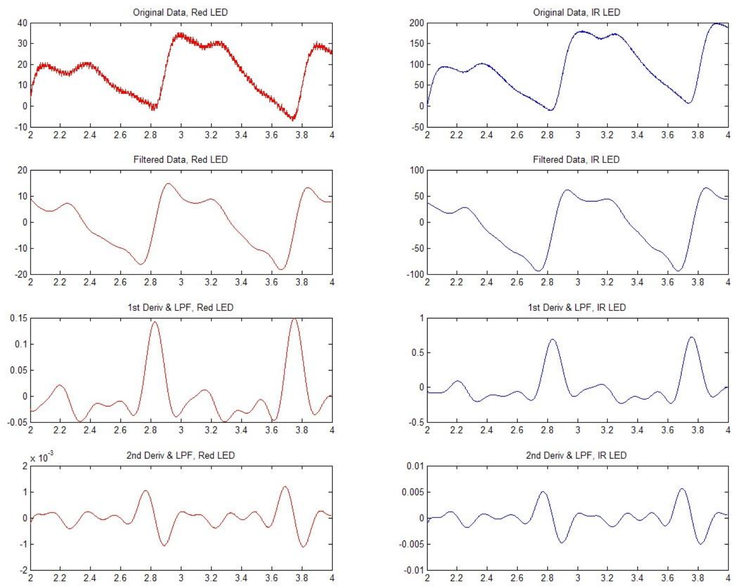
DCM02

An influence of vascular aging on the contour of the peripheral volume pulse in the upper limb is well recognized. Aging is accompanied by increased stiffness of large elastic arteries leading to an increase in pulse wave velocity (PWV). Premature arterial aging, as determined by an elevated aortic pulse wave velocity is now recognized as a major risk factor for ischaemic heart disease. It has been demonstrated earlier that the contour of the PPG signal contains similar information to that of the peripheral pressure pulse. Because the peripheral volume blood flow pulse is essentially due to a propagating pressure pulse, the time course of the signal indicating flow changes bears a relationship to pressure changes. The contour of the PPG signal is determined mainly by the characteristics of the systemic circulation, including pressure wave reflection and pulse wave velocity of the pressure wave in the aorta and large arteries. As age increases, pulse wave velocity increases decreasing the time taken for pressure waves reflected from the periphery of the circulation (mainly from the lower part of the body) to return to the aorta and then to the upper limb. The stiffer the artery the faster the pulse will travel to the periphery- i.e the pulse wave velocity increases. In addition, augmentation of the forward pressure pulse wave by a fast returning reflected wave is another key feature that can be found in subjects with arterial stiffening.



PPG Domo Kit with APM Reflective Sensor

The second derivative of the photoplethysmogram (SDPPG) to study age-related indices and other risk factors for atherosclerotic vascular disease. This has proved to be particularly useful when the dicrotic notch in the PPG signal becomes less prominent, making it difficult to detect minute changes in the phase of the inflections using the pulse wave contour itself. APMKorea developed and supplies a SDPPG Kit with APM integrated dual wave(Visible and IR) reflective sensor showing obvious contours of initial PPG, 1st derivative(FDPPG), 2nd derivative PPD(SDPPG) for developers who study the contour of the pulsatile component of the PPG and calculate of certain age related indices to make the commercial equipments.



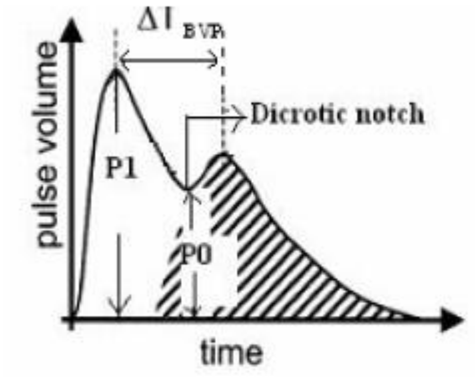
Initial PPG signal

Filtered PPG

1st derivative PPG (FDPPG)

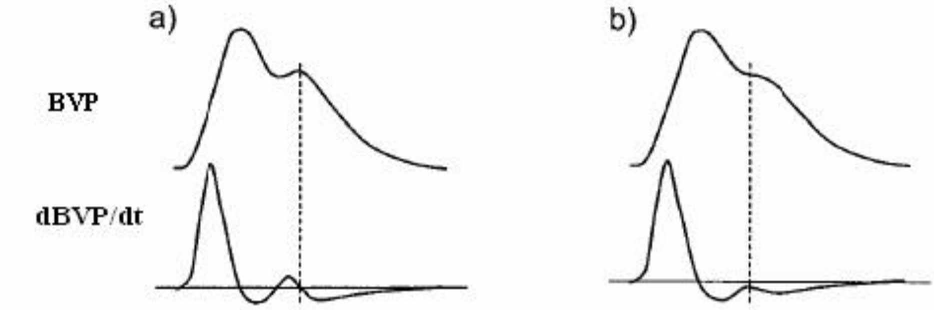
2nd derivative PPG(SDPPG)

The contour of the PPG signal exhibits an early systolic peak and a latter peak or point of inflection that occurs a short time (ΔTBVP) after the first peak in early diastole. The systolic component results from the direct pressure wave travelling from the left ventricle to the digit (finger or toe), and the diastolic component results from reflections of the pressure wave by arteries of the lower body back to the finger. The time difference between these two peaks (ΔTBVP) is a measure of the transit time between the subclavian artery and reflection sites and has been used to define a non-invasive measure of large artery stiffness.

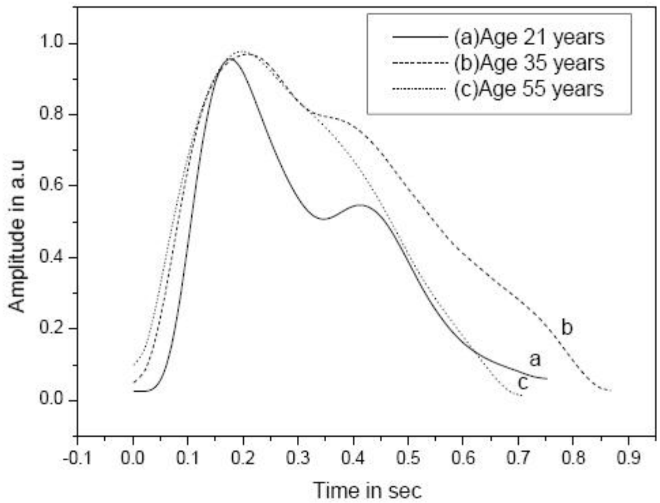


BVP recorded by measuring the transmission of IR light through the finger pulp

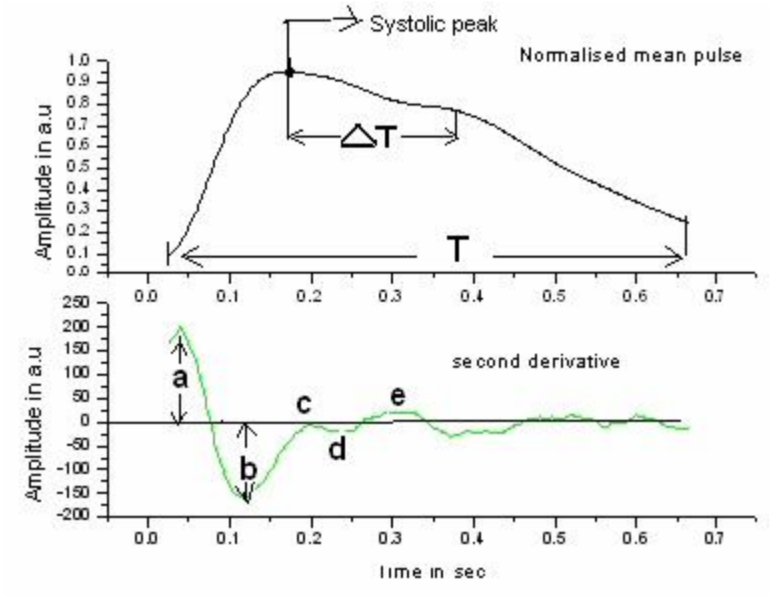
ΔTBVP was determined as the time between the first systolic peak and the early diastolic peak in the waveform. The first derivative of the mean pulse function was used to locate the peaks. The systolic peak was identified as the first zero crossing and the subsequent negative zero crossing, or positive inflection nearest to zero determined the time of the diastolic peak or inflection occurrence. Figure below shows how the systolic and diastolic peaks are identified for a given PPG signal with or without a dicrotic notch.



BVP and its first derivative dBVP/dt for waveforms exhibiting a) a diastolic peak b) a point of inflection



Mean pulse function for subjects aged 21, 35 and 55 years, Left side curve shows how the shape of the mean pulse function varies with respect to age. For younger and healthy subjects the dicrotic notch was predominantly seen whereas in older subjects owing to the increase in arterial stiffness and a faster reflected wave augmenting the forward wave the pulse becomes rounded. In our study it was noticed that the peripheral pulse has a steep rise and a notch on the falling slope in younger subjects whereas in older subjects a more gradual rise and fall and no pronounced dicrotic notch . In older subjects the pulse wave velocity is also much higher compared to younger subjects owing to the increase in stiffness index with age. From the recording of the original PPG, sometimes there is a difficulty in detecting minute changes in the phase of the inflections. So, by double differentiating the PPG, the second derivative of the PPG signal is obtained (SDPPG), which helps in more accurate recognition of the inflection points and an easier interpretation of the original signal. The SDPPG is used as a means to accentuate and locate inflection points and a specific nomenclature has been adopted, such that the five sequential waves are designated as a, b, c, d, and e. To describe the SDPPG components quantitatively, the height of each wave was measured from the baseline, the value above the baseline being positive, and those under it negative. The a, b, c, d and e waves represent the initial positive, early negative, re-increasing, late redecreasing , and diastolic positive waves, respectively. The normalized mean pulse and its second derivative in the case of a 25 year old subject is shown in Fig.3.4. Absolute values for the height of the waves ‘a’ & ‘b’ were referred to as ‘A’ & ‘B’, respectively.



Normalized mean pulse and its second derivative (SDPPG) of a 25 year old subject. The waveform of the SDPPG consists of four systolic waves (a, b, c and d waves) and one diastolic wave

Indices derived from the PPG signal

The following indices were evaluated from the recorded PPG signals using the hardware setup indigenously developed in our laboratory.

1. Stiffness Index (S.I)

Assuming the path length to be proportional to a person's height, the stiffness index has been defined as

S.I (m/s) = Body Length/ΔTBVP

Because of the complexities of the formation of the blood volume pulse, S.I cannot be considered as a direct measure of large artery pulse wave velocity. It could be simply considered as an index characterizing the features of the contour of the blood volume pulse that are determined mainly by pulse wave velocity in the aorta and large arteries, and hence by the stiffness of these arteries.

2. Minimum rise time

The minimum rise time (MRT) parameter has been defined as

MRT= (dt/dy) x (Maximum Pulse Height)

This represents the inverse of the normalized maximum rate of rise of the blood pulse volume. The MRT values for each subject in the experiment were determined using the already derived mean pulse function.

3. P0/P1 Ratio

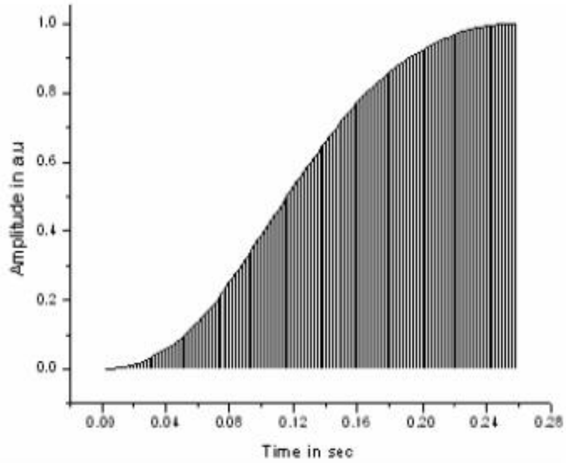
The systolic peak of the recorded blood volume pulse was located and the valley point was used to locate the dicrotic notch. From the derived mean pulse, the foot of the blood volume pulse waveform was located and was taken as the reference. The ratio P0/P1 was calculated as the ratio of the amplitude from the foot to the valley point (point where dicrotic notch is located) to the amplitude from the foot to the systolic peak. All the three indices mentioned above were derived from the mean pulse function.

4. B: A ratio

The B:A ratio was determined from the second derivative of the PPG signal (SDPPG). As shown above figure, the absolute values of the 'a' and 'b' waves of the SDPPG are taken as 'A' and 'B' respectively. This parameter is related to the distensibility of large arteries.

5. Area under the systolic peak

The area under the systolic peak (shaded area) was calculated as the area lying under the systolic peak and the foot of the wave.



6. ΔTBVP/T ratio

ΔTBVP represents the time delay between the systolic and the diastolic peaks and ‘T’ represents the time period of the PPG waveform. Indices 5 and 6 are determined from the normalized mean pulse derived from a set of PPG signals. The six parameters, namely the stiffness index, minimum rise time, P0/P1 ratio, area under the systolic peak, B;A ratio, and the ΔT/T ratio can provide a simple non-invasive means for studying the changes in the elastic properties of the vascular system. The obtained results demonstrate that the overall effect of changes in arterial properties, such as relating to arterial stiffness, can be detected non-invasively from the finger tip by examining the mean pulse shape and the SDPPG characteristics.