A New Technique for Measuring Human Stress Level

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Abstract: Various formerly implemented methods for stress measurement are initially discussed in the current paper. The most common ways of stress measurement are through checking speech, salivary amylase, oxygen saturation in arteries, skin temperature fluctuations, heartbeat rate, blood pressure, pressure at fingertips, and diversity of other methods. Taking into account the higher precision of diagnostic methods based on measurement of heart rate and fingertip pressure, the current research attempts to design a combined technique for improving the measurement and diagnosis accuracy. Variations in heart rate and fingertip pressure are considered here. As such, direct impact of stress is studied on automatic nervous system and parasympathetic nervous system of body, and subsequently, measurement of the two aforementioned fluctuations are taken into account. On this basis, stress fluctuations generally cause changes in heartbeat frequency per minute. Through examining fingertip pressure in the states of presence and absence of stress, it is revealed that rate of fingertip pressure follows a second-order partial differential equation based on Newton's second law. By recording the respective data and combining and analyzing the two abovementioned techniques, a higher precision in stress measurement was achieved compared to the already proposed methods. For this purpose, heart rate and force converters are merged and accuracy of stress measurement improves from 60% to 78%, which in turn offers a novel growth and transformation in the scope of stress level measurement.

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Introduction

Stress normally originates from a major root that might include psychological tortures and/or momentary changes in mental mode based on different events and abnormalities. Stress is regarded as an essential threat to human health. Today, along with advances in technologies and facilities, the dependences, and consequently, stress for losing them have grown proportionally.

The examples of such disorders are: social abnormalities, cyber offences, and likelihood of personal information disclosure, all of which turn the stress into a threat to individuals. Nonetheless, stress is also an intricate subject to investigate its consequences such as cardiac diseases, diabetes, asthma, and depression. Techniques applied to measure stress level in people are discussed in the present study, which will help determination of stress level for different individuals under variety of conditions in medical equipment science. The findings of the current research can have applications in cases like controlling stress level of car drivers and admonishing to prevent them from driving, avoidance of performing surgery on individual with high stress until stress alleviation, and accordingly, prevention from heart attacks and similar incidents.

Speech examination is among the formerly studied methods for stress level measurement [1]. This method deals with application of Fourier series on power coefficient at frequencies with linear short wavelengths in two domains of time and frequency. The results indicate that this method features a higher accuracy in diagnosis of stress type as compared to the similar non-linear case. Another technique focuses on amount of saliva amylase and offers a simple computational method for stress measurement [2]. In the third method, a multi-sensor system evaluates oxygen saturation in arteries for different body organs such as ear, mouth, and fingers in order to measure and diagnose the stress [3]. Some software packages have been also implemented to estimate stress level using sensors for measurement of skin temperature [4]. In an alternative approach, different states of human stress are simulated based on fuzzy logic [5]. Expensive sensors are applied for receiving the needed signals in this method [6]. Another technique measures the stress level based on the stressed person's fingertip pressure exerted on a rolling and flexible cylinder [7 and 8]. In this method, dynamic response of the flexible segment of cylinder as a result of the exerted pressure is taken into consideration. In addition, other methods can also serve as novel solutions for expansion of this scientific scope, including detection of: eye flashing frequency, change in skin color [9 and 10] and (Electro-Dermal Activities or EDA), voice tone alteration [11] and tremors in voice induced by stress, change in heart rate (HR), different indices of Heart

Rate Variability (HRV), blood pressure variations, muscular tension, respiration [12 and 15], and also presence of local tremors or exceeded moisture on the skin.

Preface:

A new method of combining heart rate changes (and hence number of pulses per minute) and pressure variations at fingertips are analyzed form both the mechatronical and biomechanical aspects in the present paper. All parameters are considered in one collection so as to improve the measurement accuracy. The procedures, of course, must be carried out using covered or mounted sensors to avoid disturbing the person and/or attracting people's attention in public places. For example, EDA technique is among the strongest andmost recognized methods in stress diagnosis and measurement. However, the electrodes must be mounted on the palms or fingers in this method, which might lead to restriction of the tested person's freedom and eventually his/her fatigue. Continuous blood pressure measurement is another technique which requires use of pressure recording apparatus. The pressure in this method is normally measured through vein compaction by the air pressure or insertion of a needle into the arteries, which is again a difficult and disturbing procedure. Since heart rate can by itself provide plenty of information about and cover all of these factors, the current method is accordingly designed based on calculations and analyses on heart rate and stress level measurement through its variations.

Automatic Nervous System (ANS) is a part of body's nervous system which helps as a controlling mechanism to maintenance of body at a stabilized condition (homeostasis). ANS consists of two major branches: sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). The SNS branch helps the body to prepare for taking action in response to potential threats. The PNS system is most active when the person feels no challenge or stress, and, maintains the body in a state of relaxation and tranquility. Both major nervous branches directly affect the heart rate but PNS reduces its value. Unfortunately, heart rate fluctuations cannot be easily measured in terms of SNS and PNS values. In fact, it is not easy to determine reduction or increase in which one causes such responses on the heart rate. Of course, pulse rate can be also examined instead of heart rate. Pulse is actually a wave transferred centrifugally from the origin of body arteries or heart to the smaller and peripheral arteries. In other words, heartbeat rate emerges as pulse in the arteries. Changes between each two heart beats shall be examined in order to precisely detect the pulse frequency, which is known as Heart Rate Variability (HRV) analyses. According to the current study, two important frequency spectra can be assumed. First, frequency interval between 0.04 to 0.15 hertz caused by combination of SNS and PNS and their regular and average functions, and second, the frequency interval between 0.15 to 0.4 hertz created by PNS activity alone [16].

Assessment and Estimation

SNS and PNS create a one-dimensional chain which easily begins varying due to the slightest change in stress so that a mutual correlation is established i.e. increase in activity of one branch will be followed by reduced activity in the other one. The following figures simply illustrate this phenomenon [17 and 18].

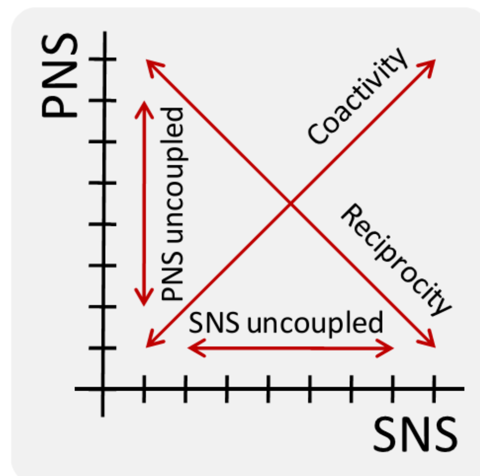

Figure 1. SNS and PNS variations and their interaction

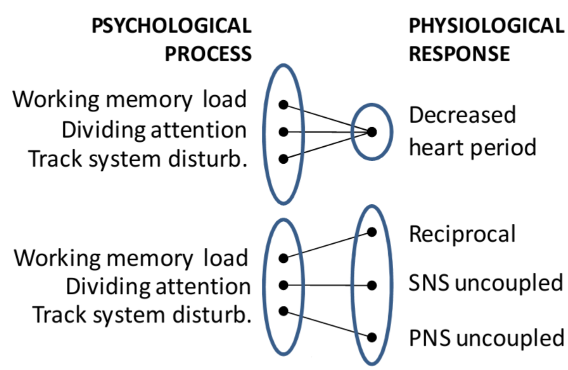

Figure 2: Mutual effect of PNS and SNS and heart rate control [18]

Therefore, SNS and PNS variations, and as a result, stress level in the body can be generally determined if heart rate or pulse is evaluated. Furthermore, fingertip pressure can be also taken into account in order to improve efficiency and lower the error percentage.

Measurement and Calculation of Fingertip Pressure

Increased stress in turn causes changes in fingertip pressure exerted on the objects. Such reaction can be analyzed according to the respective equation and based on Newton's second law for measuring the force/pressure exerted by the fingertip. The second-order differential equation with partial derivatives is [19]:

(1)

$$\frac{\partial^2 u}{\partial t^2} = \frac{F}{\rho}\frac{u_x(x+dx,y_1)-u_x(x,y_2)}{dx} + \frac{F}{\rho}\frac{u_y(x_1,y+dy)-u_y(x_2,y)}{dy}$$

The following final result is obtained after solving the equation above [19]:

(2)

$$u_{m,n}(x,y,t) = sin\left(\frac{mx\pi}{a}\right) sin\left(\frac{ny\pi}{b}\right) \cdot \left[B_{m,n}cos\left(\lambda_{m,n}\right) + B^*_{m,n}sin\left(\lambda_{m,n}\right)\right]$$

Where; "m" and "n" represent different operational states and "a" and "b" are length and width of fingertip, respectively. B and B^* are the constants imposed by initial conditions of the problem. .$\lambda_{m,n}$ is the Eigen-value obtained via the equation below[19]:

(3)

$$\lambda_{m,n} = k\pi\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

Where; F denotes the force exerted on the surface in Newton per square meter [19].

Measurement and Calculation of Heartbeat or Pulse Rate

Using similar equations, heart or pulse rate can be also directly measured. The HR-related equations might obey a former memory known as the model memory in the present research. This memory is able to retain different mental states of the person in stress-free or stressed conditions and help the current equation to yield a more precise prediction and estimation. Primarily, a non-linear system needs to be totally identified and output condition of the system shall be clearly specified. The following equation is applied for this purpose:

(4)

$$y(t) = k_0 + \sum_{\tau=0}^{M-1} k_1(\tau)x(t-\tau) + \sum_{\tau_1=0}^{M-1}\sum_{\tau_2=0}^{M-1} k_2(\tau_1,\tau_2)x(t-\tau_1)x(t-\tau_2) + \cdots$$

In this equation, y (t) is the same as system output and x (t- τ) is system input with time delay of τ and model memory of M. This equation can be written in matrix form because it assumes a second-order structure similar to the one for calculation of fingertip pressure:

(5)

$$y(t) = X^T(t)QX(t)$$

$$where\ X(t) = \begin{bmatrix} 1 \\ x(t) \\ \vdots \\ x(t-M+1) \end{bmatrix} and\ Q = \begin{bmatrix} k_0 & \frac{1}{2}k_1{}^T \\ \frac{1}{2}k_1 & k_2 \end{bmatrix}$$

Due to symmetry of Q matrix, an equation can be defined where □s are Eigen-values of matrix yielding a result as below:

(6)

$$y(t) = X(t)^T QX(t) = X(t)^T R^T \Lambda RX(t) = U(t)^T \Lambda U(t)$$
$$= \sum_{i=0}^{M-1} \lambda_i u_i^2(t)$$

And "u" value is evaluated through the following convolution:

(7)

$$u_i^2(t) = \{v_i * X(t) + \mu_{i,0}\}^2$$

$$where\ v_i = [\mu_{i,1} \quad \mu_{i,2} \quad \cdots \quad \mu_{i,M}]$$

Thus, the output value follows the equation below with a close proximity to the real value:

(8)

$$\hat{y}(t) = \sum_{i=0}^{S} \lambda_i \{v_i * X(t) + \mu_{i,0}\}^2$$

System Designing and Implementation

Using a micro-controller together with sensors for detection of heart rate, pressure and also via analysis of their output values in equations of fingertip pressure and heart rate calculations, and, according to the obtained models and equations, a block diagram with a relatively desirable output and high accuracy can be reached for stress level measurement. General scheme of this block diagram is considered as follows taking into account the memory as well as wireless system for avoiding the physical hindrance of the equipments for the tested person [20].

The next figure can be supposed in the sensor detection section of block. This figure shows two sensors which are connected to a micro-controller. One of the sensors measures the force/pressure exerted by the fingertip on the silicon surface, and the other sensor records pulse rate per minute through the fingertip [19 and 20].

The input data can be introduced to micro-controller through keyboard based on which the needed changes can be made for different states or for resetting the system to repeat the test. Instantaneous stress value outputs can be also observed on the mounted monitor. Of course, different commands might be issued thanks to the program installed on the micro-controller. For example, when a person is driving and the stress value exceeds the pre-defined limit, the command can be issued to stop the car and let the driver get rest, preventing from subsequent risks for the driver [21].

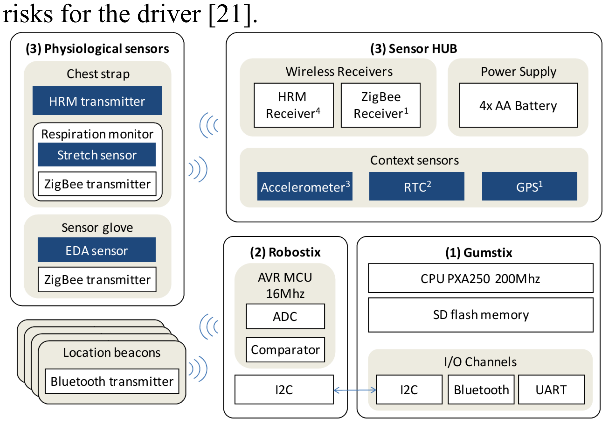

Figure 3- General block diagram of stress measurement system

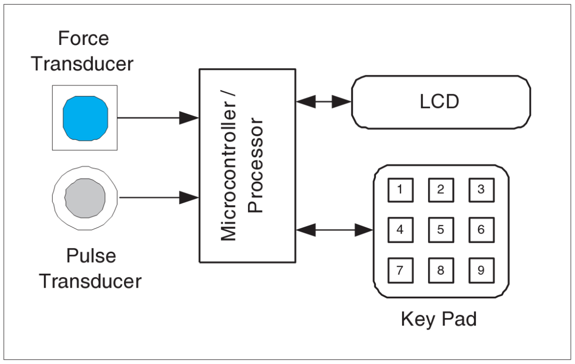

Figure 4- Block diagram of sensors

Circuit Design and Implementation

Two main signal-regulating circuits are required for modifying the output signal from converters to micro-controller inputs. The first and second circuits are respectively used for force/pressure and pulse converters. The force/pressure converter is an 1856 model manufactured by Sensor Techniques Company. The output of this converter is a voltage in the range of 0 to 100 mV resulting from an equivalent pressure of 0 to 25 psi [23]. The interface circuit for this converter is illustrated in the next figure. The booster is adjusted in a way that even extremely small voltages are amplified.

This circuit is designed so that detectable voltages are sent to micro-controller as force or pressure values. Hence, it is capable of detecting even the smallest changes in the input and amplifying the signals to the extent that they can be easily read by the micro-controller.

The extent of this amplification is such that it can even detect the smallest values like the stress caused by harsh horn of an automobile. Sensitivity of the output system is of course adjustable in a manner that provides suitable responses for variety of stresses.

Force/pressure versus the generated voltage in this circuit is used for predicting the amount of the exerted force/pressure based on the output voltage in micro-controller. In this diagram, the correlation curve is fitted on the main plot in the form of a straight line with fixed slope.

As illustrated in the following figure, the second circuit regulates the output signal of the sensor which detects fingertip pulse. Pulse converter is a piezoelectric device that transmits its output voltage in the range of 50 to 300 mV through a BNC connector. This signal is boosted in the circuit and sent to a **comparing circuit**. Output of the **comparing circuit** is a series of digital pulses which are transmitted to the micro-controller for counting the pulse beat frequency per minute. It must be noted that the whole circuit is supplied with a 9Volt battery.

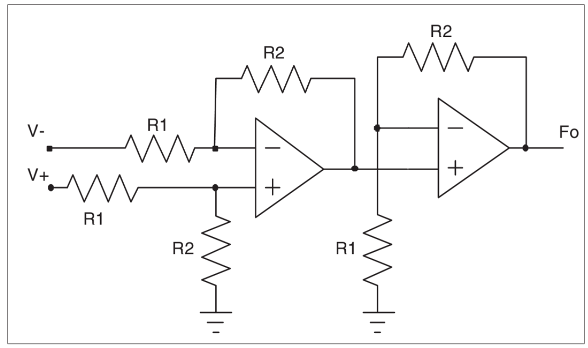

Figure 5- Force/pressure converter

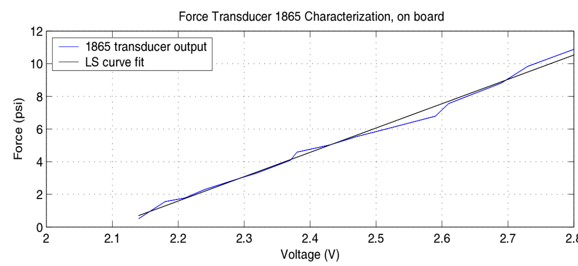

Figure 6- Plot of force/pressure vs. the generated voltage

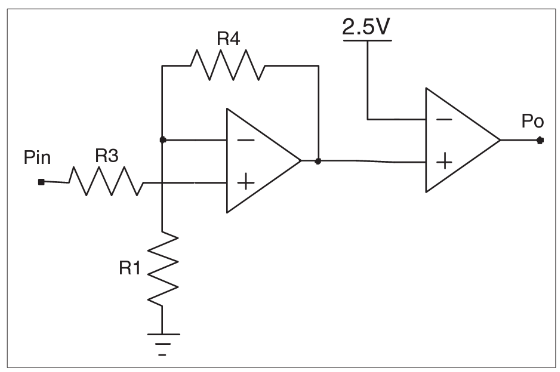

Figure 7-Pulse beat converter

The micro-controller used in the circuit is PCI16F877A manufactured by Microchip Company. This controller contains an 8 KB programmable memory. Code of the defined algorithm is converted into C program in the same way as the needed equation. A 4-Mhz crystal is also used for encryption operation of micro-controller. Two 8-bit digital ports and two single-canal analogue-to-digital converter ports are also incorporated in this sample. Analogue-to-digital converter ports receive output of two signal-regulating circuits for measuring force/pressure and pulse while connected to a keyboard and monitor from another side.

Density and power spectral density (PSD) were compared and also the possibility to assess the tested microscopic points and density as well as resolution option were utilized in order to better describe the accuracy of the current method in heart rate variability measurement and monitoring versus conventional Electro-Cardio Graphic (ECG) systems. Memory of the mathematical model is selected to be 120--- and the test is run up to 300 seconds, which perfectly demonstrates Heart Rate Monitor (HRM)'s accuracy in comparison with ECG:

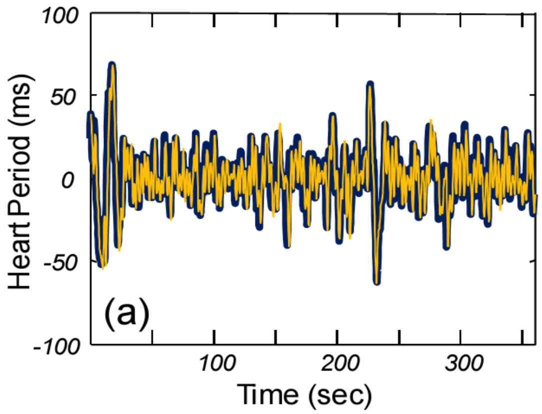

Figure 8 - Heart rate plot and comparison of ECG and HRM

According to the analysis, it was revealed that correlation coefficient of these two signals equal 0.99 suggesting very high measurement accuracy in HRM technique. Heart rate variability (HRV) also had to be studied, and, comparison of ECG and HRM led to the following result.

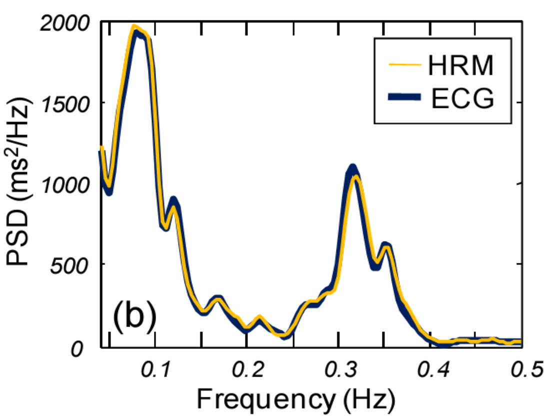

Figure 9 – PSD profile versus frequency variation

Conclusions

As observed in force/pressure vs. voltage plot, the correlation between output voltage and the exerted pressure/force is linear and monotonous. Therefore, a first-order equation based on the data received from force/pressure converter can be applied instead of storing a table for values and occupying memory in the micro-controller. Equation of the respective plot which derives the force from voltage is a curve as below:

$$PSI = 14.8993V - 31.1837$$

A comparison was made to show accuracy of system's performance and closeness of the fingertip pressure data and heart rate measurement results. Each of the aforementioned equations were separately executed by the micro-controller and ensured closeness of the results obtained from the analytical equations. Thus, combination of these two techniques strongly improves the stress level measurements and will remarkably reduce the system error. This test was carried out on 30 persons whose specifications completely differed in terms of age, gender, and weight.

In the subsequent parts, the distribution graphs illustrate the four operational states based on the function implemented for force/pressure and pulse frequency measurement. The next figure represents one of the operational states.

The former graphs are plotted as a solution to stress diagnosis based on force/pressure measurement. In the first state (the left upper graph), three distinctive classes are well distinguishable. Number (1) represents relaxed or stress-free state; number (2) signifies slightly anxious or having a little stress, and finally, number (3) is indicative of a completely anxious or stressed state (mood).

In the same way, the following figure can be analyzed for the method designed based on pulse frequency per minute (Figure 11).

The results in these two diagrams are somewhat similar to each other. The success chance in the first method was 60% for diagnosing different states of a person out of the three choices, and 78% for general stress diagnosis, which is largely similar to the second method. In the second method, the person will be in the relaxed mood if his pulse frequency is below 80 per minute; the person can be regarded semi-anxious if the pulse frequency lies in 80-90 (per minute) interval, and anxious in the case that pulse frequency exceeds 90 per minute. Obviously, a more rigorous classification is required and the number of samples shall be also enormously increased for improving the accuracy and defining criterion for evaluating and measuring stress level. Nonetheless, combination of these two techniques will contribute to improvement of measurement accuracy besides prevention from erroneous warnings of the system, which in turn will provide a tremendously precise recording of the stress value. Furthermore, sampling speeds of heart rate and fingertip pressure techniques are high leading to quick response and taking the pre-defined action immediately after induction of the stress to the person.

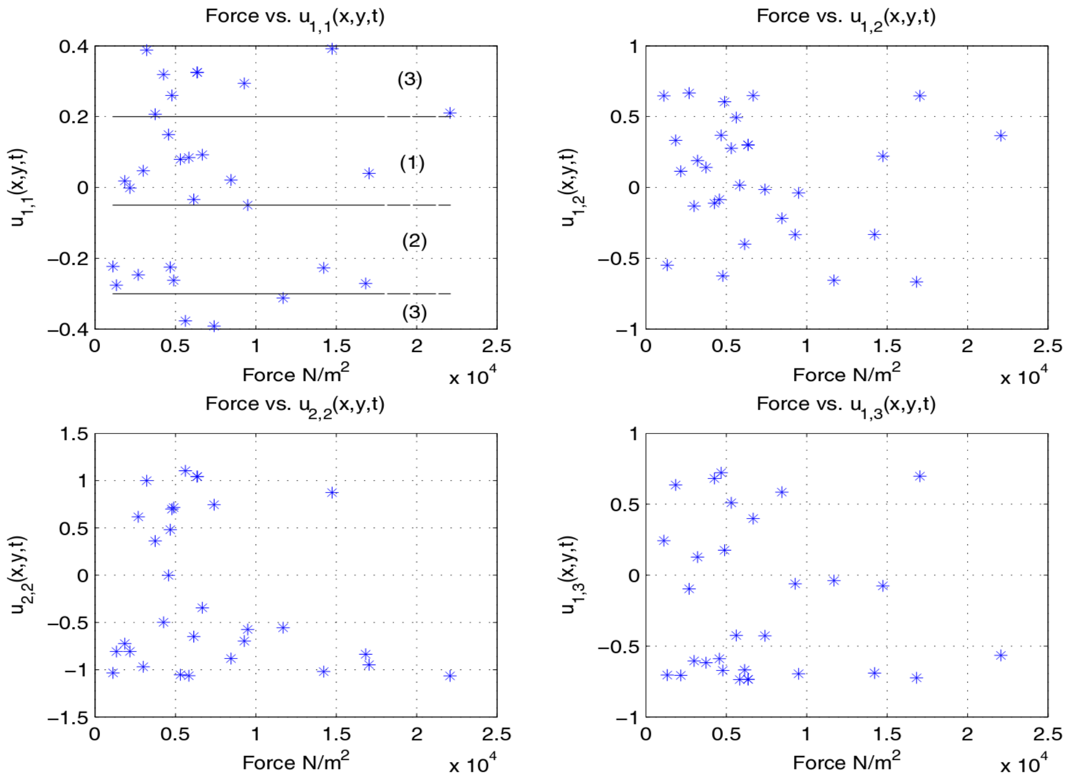

Figure 10 – The samples taken based on changes in fingertip pressure induced by stress

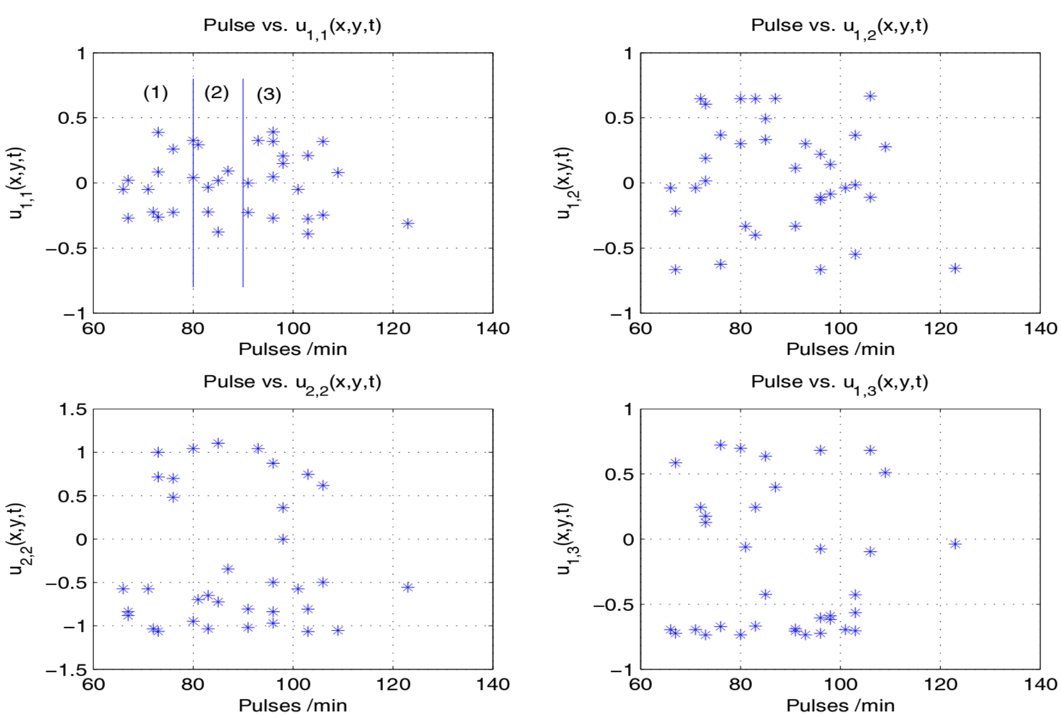

Figure 11 – The samples taken based on pulse variations caused by stress

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