A Non-Invasive Technique For Pulse Diagnosis Through Pulse Auscultation System

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Abstract:

The Diagnostic Techniques Of Indian Medicine System Takes Its Root From Understanding And Analyzing The Three Radial Pulses. Pulse Or Nadi (Sanskrit Term) Is A Vital Movement Of Energy, That Is, Life Which Advances Along The Fine Medium Throughout The Human Body That Helps The Physician To Feel And Understand The Flow Of Blood All Along From The Heart. Nadipariksha Is An Ancient Ayurvedic Technique Of Diagnosis Through The Pulse Or Nadi. It Is A Powerful Way Of Diagnosing Physical, Mental And Emotional Imbalances As Well As Diseases. This Non-Invasive Technology Aids In Reaching The Root Cause Of Bodily Imbalances And Health Disorders In Addition To Addressing The Symptoms.

Keywords— Pulse Diagnosis, Ayurveda, Nadi, Sensor, Microphone, Auscultation

I. Introduction

The Science Of Ancient Traditional Medicine Presents That The Root Cause Of Disease In The Human Body Is Due To The Imbalance Of Tri-*Doshas* (*Vata, Pitta, Kapha*) Or *Panchamahabhutas* (Five Elements). The Equilibrium Of These Three *Doshas* Is Quite Important To Maintain Proper Functioning Of Every Aspect Of Physiology. In Other Words, Any Imbalance In The Proportion Of These *Doshas* Causes A Disorder In The Human Body. The Primary Factor To Cure And Maintain Our Body In Good Health Condition Can Be Attained Through The Balance Of These *Doshas* Which Helps To Regain The Balance In The Human Body. The Simple And The Innate Way To Diagnose Diseases And To Regain Balance In The Body Can Be Accomplished Through A Natural Way Of Diagnosis Termed As Pulse Diagnosis (Pd) Which Proves To Be Effective And Result Oriented. Pulse Diagnosis Is A Method Of Examination Of Pulse Colloquially Known As *Nadipariksha*. It Is A Non-Invasive Method Used To Ascertain The Health Of A Person By Analyzing The Pulsating Waves Of The Body. The Medical Practitioner Senses The Pulse By Firmly Holding At Each Of The Three Radial Points To Monitor The Health Condition And Senses Different Bio-Signals In The Human Body. The Examination Of The Pulse Performed By The Practitioners Have To Be Profound And This Requires A Lot Of Experience In Pulse Reading. Hence, There Is A Need To Develop A Pulse Diagnosis System To Obtain Accurate Reading Of The Pulse To Diagnose The Disease.

This Work Introduces A Novel Model Representing The Pulse Auscultation System. The System Involves A Microphone (Termed As Mic) Basically Used To Sense And Measure *Nadi*, That Is, The Acoustic Waves That Can Be Sensed And Detected On The Wrist Joint, The Joint Between The Radius And The Carpus. This Condenser Mic Or The Microphone Records The Signal And Sends For Filtering Process For Reducing The Noise. The Filtered Signal Is Amplified To Obtain Beneficial *Nadi* Patterns. This Output Is Sent To An Oscilloscope Which Is Used For Display And Storage Of The Waveform In The Analog Form. This Output Is Delivered To A Computer To Perform Signal Analysis For Identification Of The Root Cause Of The Disease Through Pulse Diagnosis. The Study Is An Observation Of The Precept Of Traditional Ayurvedic, Chinese Medicine Techniques Related To Pulse, Wherein The *Nadi* Signals At Positions Stated As (*Vata*) "*Cun*", (*Pitta*) "*Guan*" And (*Kapha*) "*Chi*" Of The Right Hand Are Subjected To Avid Measurement During The Process Of Lift, Search And Press Operations. The Pressure Of The Pulse Does Not Affect The Display Of Any Changes Occurring In The Pulse And Accurate Waveform Signals Are Obtained. This Is Because The System Is Designed To Collect The Signals Of Sound Vibrations That Are Caused By The Pulse. Hence, Unlike The Current Pulse Piezoelectric Sensor Devices, This Sensor Is Unaffected By The Application Of Pressure. The Pulse Signal Thus Obtained Is An Experimental Evidence For Traditional Chinese Medicine (Tcm) Methods. This Work Also Endeavors A Unique And Innovative Circuit That Is Designed With The Application Of An Active Filtering Method. The System Also Yields High Precision With Less Cost With An Overall Simple Circuitry.

ii. Related Work

The Traditional Method Of *Nadipariksha* By Human Fingers Relies Entirely On The Doctor's Own Experiential Judgment, Which May Be Affected By Various Environmental Conditions That Include The Measurer's Own Sensibility Fluctuation. Therefore, The Quantification And Standardization Of The Pulse Diagnosis Is An Urgent Need, Which Requires The Transformation Of Doctors' Subjective Feelings Into Objective Physical Quantities. Indeed, Some Efforts Toward The

Quantification And Standardization Are Ongoing Research Activities. For Example, Pulse Diagnosis Systems Based On The Arrays Of Piezo-Resistive Sensors [3] Have Been Developed And Upgraded. Clinical Data Using Pulse Diagnostic Instruments For Statistical Purposes Are Collected And More Fundamental Studies Such As The Blood Flow Dynamics Along With The Radial Artery Are Under Investigation [12]. Yet There Has Been No Pulse Diagnosis Device That Is Mature Enough For Clinical Applications Which Reflects A Patient's Physiological And Pathological Changes Objectively Like Ecg Does.

The Present Pulse Diagnosis Devices Mainly Consist Of Piezoelectric Measurement Methods Which Have Few Drawbacks. The Primary Disadvantage Is When The Sensor Comes In Contact With The Pulse Or *Nadi* Through The Sensor's Head, The Tensity Of The Skin And The Soft Tendon Or Ligament Are In Concurrence. Also, The Arterial Axial Tension And The Muscular Radial Pulse Show Persistent Reactions On The Head. The Next Disadvantage Is That It Is Hard To Eliminate Tensile Impacts While Measuring The Radial Power Stroke Of The Vessel. This Prevents The Distinguishing Capability Occurring Between The Characteristics Of Pulse Related To Axial Power Stroke And Vascular Tension Of The Pulse. However, The Drawback Lies In When The Pressure Is Applied By The Sensor On The Pulse That Is Measured Along The Head Of The Sensor; It Incites A Deformation As A Result Of Resistance Offered By The Skin And The Soft Tendon, In Addition To The Coercion On The Head That Results In Many Different Computation Errors.

Pulse Diagnosis Has Been Extensively Used In Tcm And Ayurveda For Thousands Of Years. Of Late, More And More Researchers Have Developed Interest In Computerized Pulse Diagnosis Where Sensing Techniques Are Used To Acquire The Pulse Signals And Machine Learning Techniques Are Adopted To Analyse The Health Condition Based On The Acquired Pulse Signals [13]. A Number Of Sensors Have Been Employed For Pulse Signal Acquisition, Which Can Be Grouped Into Three Categories: (I) The Pressure Sensor, (Ii) The Photoelectric Sensor, And (Iii) The Ultrasound Sensor. Pressure Sensors Are Adopted In Pulse Diagnosis To Imitate The Procedure Of Tcm [6]; Photoelectric Sensors Are Adopted Mainly Because Of The Fact That The Photoelectric Sensors Are Easier To Make; The Ultrasonic Sensors Are Usually Adopted For Their Robust Interference [4].

iii. Methodology

The Objective Of The Research Work Is To Develop A Real Time Non-Invasive Sensor Which Senses The Radial Artery (Three Radial Pulses) And Provides Accurate Reading Of The Pulse For Identifying The Root Cause Of The Human's Disease. A Patient's Physiological And Emotional Diagnosis Are Performed By Acquiring Radial Artery Signal Measured By The Sonic Microphone Sensor Module. In This Work, The Pulse Sensor Incorporates A Microphone Sensor As A Sensing Unit And Uses High Order Filtering To Eliminate The Background Noise. The Exterior Design Of The Sensor Imitates The Structure Of A Pen. The Tip Of The Sensor Holder Is A Cone Like Structure And The Microphone Sensor Is Placed At 8.5mm From The Tip Of The Sensor Holder. The Acquired Signal Is Sent To The Hardware Unit And A Filter Is Designed To Get The Required Signal By Eliminating Noise. The Final Artery Signal Is Collected And Used For Further Analysis. During Experimental Validation, This Sensor Was Used For The Measurement Of The Pulse Waveforms Which Was Held At Different Positions And Depths With Respect To The Radial Artery On The Wrist Pertaining To The Necessities Of The Diagnostics.

This Work Exhibits A Novel Pulse Auscultation System (Figure 1), Wherein The Pulse Receiver Consists Of Condenser Amplifier Or Microphone Which Is Used As The Pulse Deflection Sensing Element. For The Measurement Of This Signal, A Little Force Has Been Applied On The Microphone To Touch The Measuring Point Of The Pulse Via A Cone Shaped Tube. Later, The Measurements Are Made At Various Locations Around These Points, For The "*Vata*", "*Pitta*" And "*Kapha*" Positions Used In (Ayurveda) And Tcm Pulsing Modes, And Various Reaction Signals Are Drawn And Recorded.

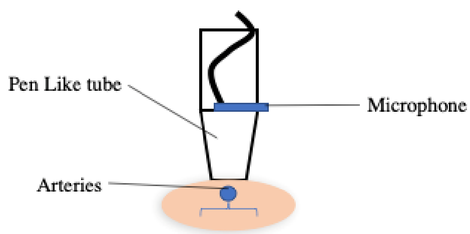

Figure 1. Pulse sensor

Figure 1: Pulse Auscultation System

The System Which Has The Pulse Auscultation Captures The *Nadi* Signal, Which Is The Direct Reflection Of The Pulse Beat. This System Exhibits Extraordinary Sensitivity And Accuracy With Respect To The Pressure Applied To It, In Spite Of The Noise Caused Due To Pulse Strokes Of The Condenser Mic, When Compared To The Present Piezoelectric Sensing Methods. Hence, The Sensor Is Unaffected By Any Kind Of Pressure Thereof Displaying The Pulse Variation With The Same Accuracy, Irrespective Of The Type Of Pulse Pressure Applied. [11, 12].

Pulse Measurement

Pulse Is A Significant Movement Of Energy Which Means The Life That Progresses Through A Fine Medium Throughout The Body, Enabling The Physician To Experience The Way The Blood Flows In And Out From The Heart. The *Nadi* Signal Begins From The Heartbeat Resulting In Contraction And Relaxation Of The Blood Capillaries. The Skin's Top Layer Pertaining To The Vessel Creates A Pressure On The Pulse Along With Its Fluid Flowing Internally And With The Components Present Within The Wall Of The Vessel Which Together Slam And Strike Against Each Other. The Proposed System Has Three Segments. The First Segment Is Structured As The Transmitter Used For Sensing Operations. The Second Is The Processor Used For Processing Of Pulse Signals. The Third Segment Is Meant For Storage And Display Of Pulse Signal Waveforms And Along With This, A Peak Signal Identification Process That Has A Pulse Signal. Design Section Used For Acquisition Of Circuit Signals Which Carries Out Reduction And Amplification Of The Analog Signal Via Band-Pass Filtered Noise. Later, This Waveform Is Displayed And Stored Using An Oscilloscope. This Waveform Is Also Sent To A Computer To Execute The Peak Detection Algorithm.

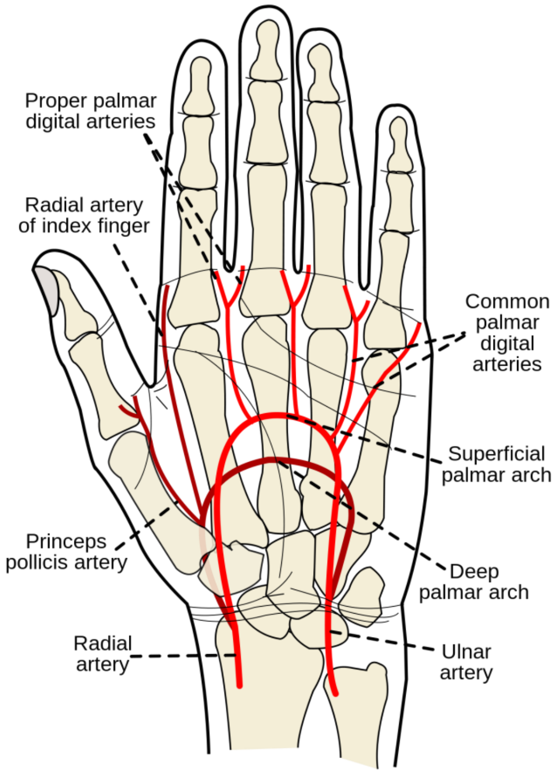

Figure 2: Palm Side View Exhibiting The Sensing Position

The Measurement Of The *Nadi* Signal Is Taken At The Radial Artery. Figure 2 Shows A Palm-Side View Which Exhibits The Sensing Position (Marked Circle) On The Radial Artery By The Sensor Module. Figure 3 Is The Sensor Proposed. The Radial Artery Is Considered For Measurement At Position 1 (Which Is From The Left Edge Of The Wrist 2 Cm ± 1 Cm).

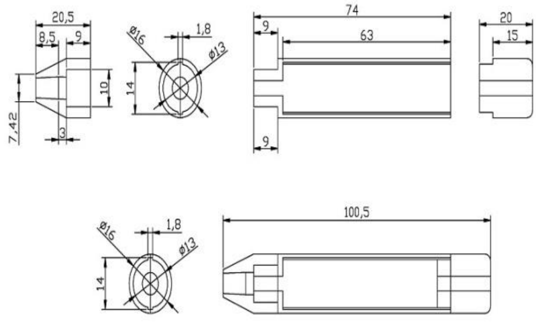

Figure 3: Proposed Sensor

The Developments In Modern Electronics And Computer Technology Have Allowed Creating A Computerized System

For Recording Pulse Characteristics In Real Time And Visualizing Pulsograms On The Display, In Addition To Enabling Processing And Analysis Of The Data To Obtain Diagnostic Conclusions About The Human Body State. With The Help Of The New And Efficient Way Of Pulse Reading With The Help Of The Proposed Sensor Module, It Is Possible To Widely Use The Pulse Diagnosis Method, Which Proves To Be The Most Accurate And Objective Method In The Practice Of Present-Day Doctor. The Sensor Attributes And Their Values Are As Shown In Table 1.

Table 1: Sensor Attributes And Their Values

Sensor Attributes	**Attribute Values**
Directional Properties	Unidirectional
Impedance	2.2kohms
Current Rating	0.5ma
Sensitivity	-65dba
Operating Range	2v
Frequency	10khz

The Sensor Holder Is A Pen Like Structure Which Internally Contains The Microphone As The Sensor. The Microphone Operates At 2v And Has A Gain Of -65dba. The Tip Of The Sensor Holder Is A Cone Like Structure And The Microphone Sensor Is Placed At 8.5mm From The Tip Of The Sensor Holder As Shown In Figure 3. The Total Length Of The Sensor Holder Is 100mm. Figure 4 Shows The Acquisition Of Radial Artery Using The Designed Sensor Module.

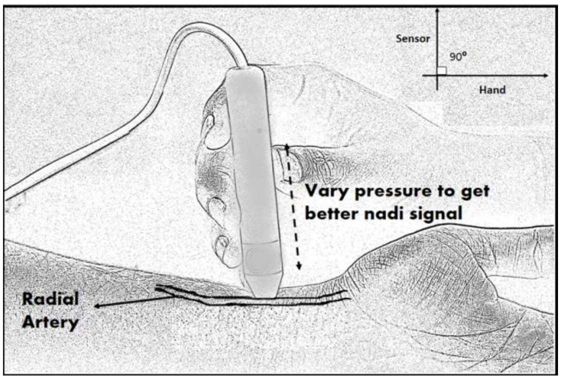

Figure 4: Acquisition Of Radial Artery Using Sensor Module

The Present Work Involves A Condenser Head Mic. This Is Shown In Figure 1. A Dc Power Supply Is Used As The Power Source Which Is A Battery. No Coils Or Magnets Are Used And There Is Only One Need To Alter The Distance That Occurs Amidst Two Separators Of The Capacitor That Causes The Generation Of Voltage. The Electret Condenser Mic Has An Electret Material And Has The Capability To Retain Charges Permanently That May Need Power Supply Required By The Capacitor. An Audible Vibration Is Produced From The Acoustic Waves That Enter Into The Diaphragm Of The Mic. Since The Obtained Substrates Are Static In Nature, The Distance Between The Diaphragm And The Back Plate Completely Changes Due To Fluctuations And Vibrations. For The Capacitance C, It Can Be Observed That

$C = A/D$ (1)

From The Above Relation, D Is The Distance Between The Separators And A Is Considered As The Size Of The Separator. Also, The Capacitance C Changes When The Distance Between The Two Separators Changes. Hence,

$Q = Cu$ (2)

In The Above Relation, Q Represents Charge. Also, The Capacitor Voltage Of The Condenser Mic Does Not Vary And Stand At A Settled Value. From The Relation, It Is Evident That When There Is A Change C The Charge Q Also Changes. Since There Is A Need To Maintain The Condenser Microphone At A Fixed Plate Voltage U, There Is A Requirement For The Extra Power To Operate. Static Equilibrium Devoid Of Electric Potential Caused Due To Electrostatic Treatment

However Is Attained. Whenever There Is A Vibration In The Diaphragm The Width Between The Two Separators Is Altered, Which Produces An Electric Potential That Creates Current Through Resistors Causing Drop In The Voltage. Later, The Acoustic Signals Are Placed For Conversion To Electrical Signals. Hence, The Condenser Mic Renders Greater Sensitivity Providing An Accurate Output As Seen In The Waveform [13, 14].

The Formula Can Be Seen As Follows:

V (Signal) = Ir (3)

I = Q/T (Time) (4)

An Input/Output Device Is A Pulse Signal Processor In Which Input Segment Is Used For Receiving A Pulse Signal Emerging From The Sensor. This Filters The Signal Obtained From The Mic Using A Signal Processor Used For Amplification. Later This Amplified Signal Output Is Sent To Oscilloscope Used To Store And Display The Signals Represented In Analog Waveform Pattern.

Most Common Filters Are The Circuits Which Are Basically Passive In Nature. Passive Filters Are Those Which Consist Of Passive Components That Do Not Need Power. The Cut-Off Frequency Depends On The Value Of Resistors And Capacitors. In The Process Of Multistage Filtering, The Circuit Is Complex Which Hinder Independent Adjustments That Are Required For Performing Cut-Off In Several Stages. Active Filters Are Different From Passive Filters, Which Uses Operational Amplifier As An Active Component Capable Of Amplifying The Cut-Off Loss To Bring At Constant Level. The Gain Along With Cut-Off Frequency Is Set Up By Resistances And Capacitances Present Inside The Circuit. Since Active Filters Render Great Influence In Providing Good Circuit Isolation Along With Harmonic Disturbances Less Than Passive Filters, This Circuit Is Employed With The Active Filter Instead Of Passive Filter That Helps To Subdue The Drawbacks Of The Passive Filter.

Steps For Measurement

In Pursuance To Circumvent Extreme Changes Contemplated And Collected As A Data During Experimentation, The Subject Has To Be Brought To Seat And Should Be Allowed To Rest For Five Minutes. During The Phase Of Pulsing, The Subject Has To Sit With His/Her Wrist Facing Up And His/Her Wrist Has To Be Kept Softly On The Pad, Along With The Pulse Wave Sensor Held At Different Positions Of Pulse Called "*Vata*" *Cun*, "*Pitta*"*Guan* And "*Kapha*" *Chi*, With A Mild Press On Each Position At Different Degrees Of Pressure To Capture And Record The Pulse Signals (*Vata* Pulse 100 G, *Pitta* Pulse 125 G And *Kapha* Pulse 150 G). In The Process Of Measurement, It Is Important To Place The Wrist Of The Subject Fixed On A Soft Pad To Avoid Any Outside Interference Without Giving A Chance For Freedom Of Movement, Which Helps To Minimize The Effects Caused Due To External Changes And Disturbances, As Seen In Figure 4.

iv. Hardware Unit

The Acquired Signal From Sensor Is Sent To The Hardware Unit. The Hardware Unit Consists Of Atmega Microcontroller Unit (Mcu), Lm358 Operational Amplifier And Ch340 Usb To Serial Converter. The Supply Voltage To The Hardware Unit Is 5v.

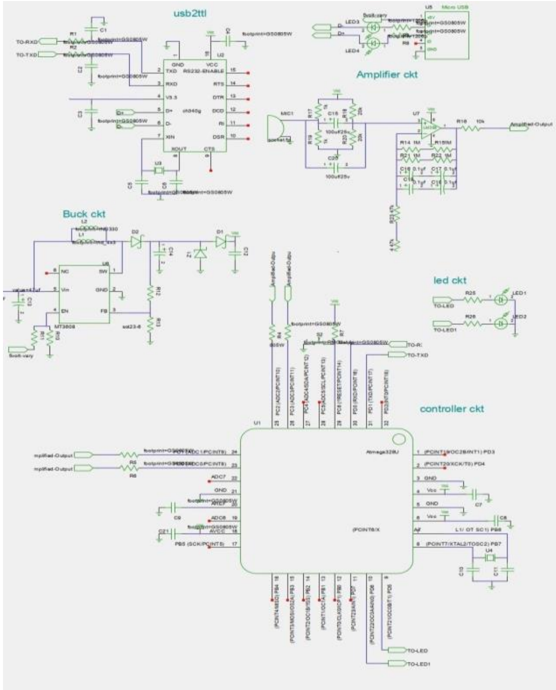

Figure 5: Processor Hardware

Two Resistors Of Values 20k, Are Connected To The Supply Ends In The Lm-358 Op-Amp. These Two Resistors Divide The Supply Voltage By Half, That Is, 2.5v And The Input Signal Variations From The Sensor (By Keeping Bias Voltage 2.5v) Is Sent To The Amplifier.

The Operational Amplifier Lm-358 Op-Amp Is Used For Designing Band-Pass Filter Circuit To Nullify The Interference Of Acute Low As Well Very High Frequency Noise. Hence, Any Disturbances Occurring Due To Physical Power Operating On The Pulse Signal Helps In The Prevention Of Aliasing. The Designed Operational Amplifier Makes Use Of The Cutoff Frequency At 0.5 Hz To 15 Hz.

Further, This Signal Output Is The Voltage (Vout As Observed In Figure 6) In Its Analog Form Obtained From The Pulse Signal Processor Is Sent To The Atmega Microcontroller Unit (Mcu) Directly And Displays The *Nadi* Signal Directly On The Computer Screen And Stores It For Further Processing. The Pulse Signal Processor Hardware Is As Shown In Figure 5. The Electronic Components Are Incorporated On The Same Circuit Board Which, In Turn, Eases And Simplifies The Task Of Measurement.

Calibration And Error Analysis

Basically, The Calibration Is Done To Check Our Measurement System In Consideration To Probe The Precision Of The Frequency Measurement System Of The Pulse Waveform Of The Human Body. In Addition, An Electric Function Generator Is Configured As A Standard Reference Target To Activate A Speaker Instead Of A Wrist Pulse Of The Human. An Ideal Electric Signal Generator Is Nothing But A Device That Causes Vibration In The Speaker, And Measures The Frequency Caused Due To Vibration Of The Speaker. Further, In The Subsequent Step, Measured Results Are Compared With The Output Waveform Of Original Signal Generator To Identify Errors In The Present System. A Basic Experimental Configuration For The System Is As Shown In Figure 4. This Is On The Basis Of Measurement Of The Vibration Frequency Of The Speaker Operated By A Function Generator Taken In The Frequency Range 0.7 Hz To 2.0 Hz At Various Degrees Of Pressure (*Vata* Pulsing Lifting100 G, *Pitta* Pulsing Searching 125 G And *Kapha* Pulse Pressing 150 G). Eventually, The Error Between The Function Generator Frequency And The Measured Speaker Vibration Frequency Output Obtained By Pulse Auscultation Measured Frequency Is Less Than 3%.

Nadipariksha Helps To Explain The Vibratory Frequency Of The Pulse Measured At Various Levels On The Radial Artery. To Ascertain Various Functions Of The Body, Fine And Refined Vibrations Are Read At Seven Different Levels Vertically Downwards. Further, When The Pulse Is Examined, Both The Physical And Mental Characteristics Of The Patient Is Revealed Apparently. The Physiological Signals Of The Body Are Traced And Detected Through Palpitation In The Wrist Which Essentially Is A Form Of Pulse Reading Technique. In This Paper, We Presented The Principles Of The Design And Analysis Of Non-Invasive Pulse Sensor Used To Acquire Three Pulses From The Radial Artery.

A Patient's Physiological And Emotional Diagnosis Is Performed By Acquiring Radial Artery Signal Taken For Measurement By The Sonic Microphone Sensor Module. This Acquired Signal Is Directed To The Hardware Unit. In The

Hardware Unit, A Current To Voltage Converter Circuit Is Used To Convert The Signal To The Voltage Of Required Form. The Converted Voltage Is Limited For A Voltage Of 2.5v Using Voltage Divider Circuitry And Further Filtered Using A Band Pass Filter (Bpf) With A Cutoff Frequency 0f 0.3-32hz. Further, Filtered Signal Is Amplified By Operational Amplifier (Opamp) Having A Gain 100. The Final Artery Signal Is Collected And Used For Further Analysis.

Test Position On The Wrist

A Ppg Waveform Obtained Is Held For Measurement On The Radial Artery. Figure 2 Is A Palm-Side Illustration Of The Sensor Designed Which Has Been Proposed And This Shows The Sensing Position On The Radial Artery Through The Sensor Module. The Radial Artery Was Held For Measurement At Position 1 (From Left Edge Of The Wrist 2 Cm ± 1 Cm).

V. Results

The Measurement Results Of Test Subject A Are Shown In Figure 6. Figure 6(A) Shows The Continuous Pulse Signal, *Vata* Pulse Of Test Subject A. The Data For A Period Of 15 Seconds Is Shown In Figure 6(B).

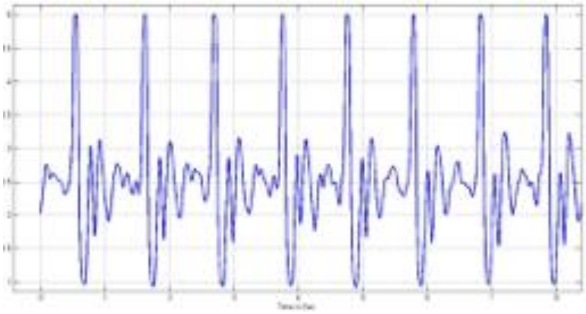

Figure 6(A): Continuous Vata Pulse Signal Of Test Subject A

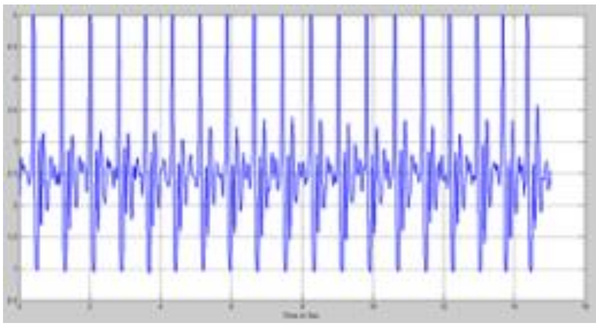

Figure 6(B): Measurement Results Of Test Subject A In 15 Seconds Period

The Measurement Results Of Test Subject B Are Shown In Figure 7. Figure 7(A) Shows The Continuous Pulse Signal, *Kapha* Pulse Of Test Subject B. The Data For A Period Of 15 Seconds Is Shown In Figure 7(B).

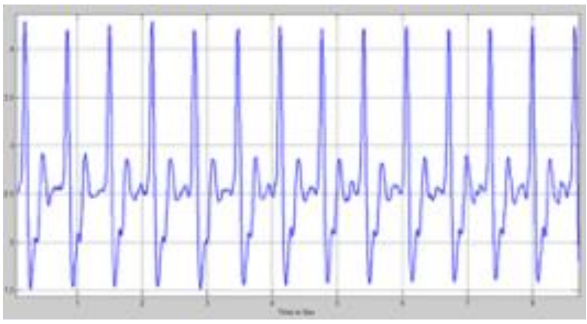

Figure 7(A): Continuous Kapha Pulse Signal Of Test Subject B

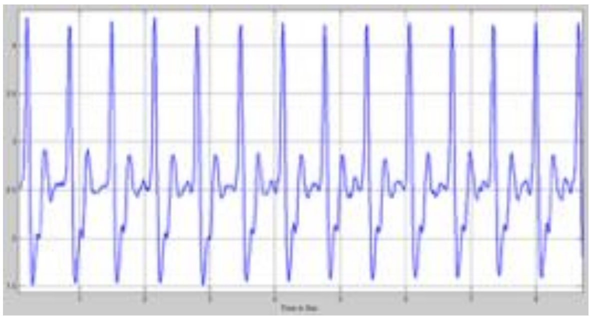

Figure 7(B): Measurement Results Of Test Subject B

An Average Of 100.4 Heart Rate Readings Per Subject Was Recorded (Total 170). Analysis By Linear Regression Revealed That The Oximeter Probe Readings Correlated Well With Proposed Pulse Diagnosis Device At All Age Groups (Table 2). A Comparison Of Mean Heart Rate At All Age Groups Showed That Oximeter Readings Were Not Significantly Different From Those Of Pulse Diagnosis.

Table 2. Heart Rate Readings

Instrument	**Subjects**	**Mean Heartrate**	**P**
Oximeter-Finger	170	99	0.91
Oximeter-Ear	170	101	0.94
Pulse Diagnosis	170	103	1

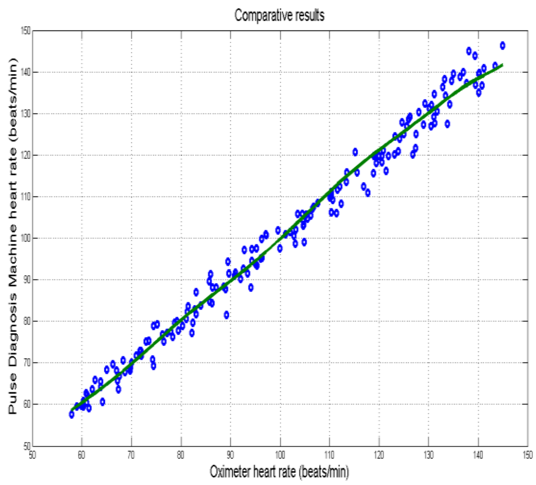

Figure 8: Graph Showing Pooled Oximeter Readings Against Pulse Diagnosis Device Readings

A Scatter Diagram Plotting Pooled Oximeter Readings Against The Pulse Diagnosis Device Readings Also Showed An Apparent Deviation Of Oximeter Readings At Heart Rates Above 120/Min This Is As Shown In Figure 8. Plotting Of Pulse Diagnosis Device And Oximetry Readings As A Function Of Maximal Heart Rate Showed That There Were No Differences Between Estimates Of Heart Rate Between The Oximeters And Pulse Diagnosis Device.

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