Critical Evaluation and Novel Design of A Non-invasive and Wearable Health Monitoring System

A Dissertation submitted for the Degree of Master of Philosophy

By

Saddedine Abbasi

September 2008

School of Engineering and Design
Brunel University

Abstract

This study is about developing a non-invasive wearable health-monitoring system. The project aims to achieve miniaturisation as much as possible, using nanotechnology. The achieved results of the project are nothing but conceptual images of a convertible watch. The system is a non-invasive health measurement system.

An important part of the study is researching the automation of blood pressure measurement by means of experiments which test the effect of exterior factors on blood pressure level. These experiments have been held to improve the automation and simplicity of BP measurements to establish a 24hr BP monitoring system.

This study proposed a medical sensor that is part of the watch system, and that is most compatible with the elderly people product preferences in the UK. The "sensor strip" is in cm range, integrating a number of MEMS sensors, for the non-invasive detection of certain health aspects. The health aspects are chosen according to how close they are from the "health vital signs", which are the first measurements executed by the doctor, if a patient is to visit him. An applied QFD study showed that the most suitable measurement technology to be used in the proposed sensor strip is the infrared technology.

In addition to the sensor strip, EEG health detection is added, which is the reason why the watch is convertible. MEMS sensors, MEMS memory and an embedded processor are selected, since that this project also includes minimising the size of a device where the utilization of nanotechnology is vital. The final result of the study is only a conceptual design of a product with a carefully selected subsystems. The software design of the product will not be further developed to become a physical prototype of a consumer product.

Acknowledgement

I have the honour to devote this study to my supervisor Dr. Qing Ping Yang. I am devoting the dissertation to him because I truly believe that he is the only person that deserves this devotion after all his faithful efforts, he has told me about most of the scientific and technological concepts mentioned in this dissertation. I am so much grateful to him; and I have to say that without his efforts with me I wouldn't have as much knowledge as I do now.

I would also like to thank the board of my School Of Engineering and Design, and to devote this thesis to them, for providing all the facilities that had dramatically enhanced my research skills.

Contents

Chapter 3 Quality Function Deployment (QFD) Evaluations of Product Subsystems.

Chapter 7 Conclusions & Future work

Abbreviations

MEMS	Micro- Electro- Mechanical -Systems.
NEMS	Nano- Electro- Mechanical -Systems.
CMOS	Complementary metal–oxide–semiconductor
QFD	Quality Function Deployment
BMI	Brain Machine Interface
BP	Blood Pressure.
BCI	Brain Computer Interface
EEG	Electroencephalogram
FMRI	Functional Magnetic Resonance Imaging
PDA	Personal digital Assistant
AE/ULT.S	Acoustic Emission or ultrasonic
IR	Infra-Red rays
NIR	Near-Infra-Red rays
FIR	Far-Infra-Red rays
EMF	Electro- motive -force
MR	Marketing Research
IEPE	Integrated Electronics Piezoelectric Technology
N	Normal level of blood pressure
RIW	Relative Importance Weight
Exp3	Experiment 3
SA	Surface Area
TSA	Total Surface Area
BPCFs	Blood pressure changing factors
AE/ULT.SO	Acoustic Emission or ultrasonics

Definitions

Watch –headphone product(proposed) : Is a type of advanced watch that has a built-in EEG system which detects brain waves when the watch takes the form of headphones worn on the head.

Headphones-top(proposed) : An embedded and miniaturised computer system which is head worn as a headphone set.

“Harmonic unity” : A design concept proposed long time ago, which states that components of any product should support each others’ functions and should not contradict each others’ functions.(Brunel university syllabus, 2005)

Video- Advertising –Automation (VAA)(proposed) : Are TV commercials (come in series) broadcasted on different TV channels where they advertise the product and improves its design at the same time, by harnessing consumer brainwave signals to detect the best possible consumer design choice in a real-time manner.

Stenoses : The contraction of capillary walls.

Brainwave Segment-origin Detection Method (proposed): Is a marketing method which uses the Conjoint Analysis method and uses EEG technology to reach the most wanted product.

Previous Effect Experiment : Experiments where other external and unknown BP-changing-factors are keeping the BP values away from the Normal BP level N = 125/85.)

Normal Effect Experiment : Experiments where other external and unknown BP-changing-factors are not present since that these experiments are held in the morning when the BP is always at its normal level N.

Unfiltered Reading : BP reading occurring when the sensor has detected the BP-changing-factor, and when the reading has a margin of error originating from that factor.

Cross multiplication of components (proposed): The process of combining product parts in groups of 2s, 3s , 4s ……. , to study the possibilities of these groups supporting each others’ functions.

BP Automation System: Is a collection of sensors and along with the watch processor which integrates their functions to detect the BP-changing-factors that affects the BP readings.

AE / Ultrasonic : The possibility of applying ultrasonics apparatus if AE methods are not applicable, since they have a very close physics,

List of Figures And Tables

Chapter 1and 2

Chapter 3

Chapter 4

Fig 4.1 (c) Inflatable device structure**,** 8/2006

Chapter 5

Chapter 6

Chapter 7

Chapter 1 : Introduction

1.1 The Main Problem

Do we need portable "general-health-measurement" devices,… and if we do ……. , do they exist in the market nowadays ?!!

There is an extreme need for such devices. Unfortunately, the available devices in the market do not meet the needs of customers towards a proper general-health measurement device. Some portable medical devices do exist in the market, but with very limited medical functions that they can't really be called "general-health-measurement". Each of these devices are so much specialised in one area of the body , which means that if at any time a patient wants to diagnose himself , checking if he has some medical problems he has to buy more than one device.

What we are trying to build in this study is a device that can measure maximum possible number of medical parameters integrated in one and only one device. The literature review results showed that such integrated devices are available in very limited numbers and types , and is produced for all ages. Additionally, the amounts of measurement parameters found in these devices are very limited.

1.1.1 The Needs for Such Integrated System And A Need For A Watch-like Device

1) A need for reliable devices for old-people : The project emphasises the urgent need for these devices only for the elderly people, where the lack of their medical awareness is life threatening.
2) A need for minimising unnecessary governments spending on old-people by financially supporting these products to be a substitute for hospital health checks :

Table 1.1.1 "Elderly As a Percentage Of The Population And A Percentage Of Total Medical Spending, 1963–2000" [1].

Year	Percent of population	Percent of spending
1963	9.4	19.7
1970	9.9	27.5
1977	10.9	34.7
1987	12.2	42.7
1996	12.7	41.5
2000	12.6	39.2

In the above table(1.1.1), it is reasonably clear that the government is consuming a lot of money on building hospitals and providing health services in these hospitals to make sure that the elderly patients are getting enough health care.

This means that a lot of old people are regularly visiting the hospitals, therefore, the daily consumption of hospitals, hospital facilities, medical services in the hospital, devices, and staff is also high. That is, the reason why we can see the rise in the "Percent of spending", as it is recorded in the above statistical table, is because year after year the government has to increase the amount of hospitals and facilities for the society since that the percentage of the elderly people are increasing too.

One solution to this problem is that the government should divert its spending on portable medical devices which may lead to reduced needs for hospitals. Hospitals are kept for serious situations and emergencies only.

If the government is to concentrate on developing portable medical devices the following areas of expenditure will be saved:

Hospitals : The cost of constructing additional hospitals that are worth millions. And the cost of space.

Medical services : Constant purchasing of consumable medical equipment (e.g. syringes, plastic items for medical tests, anti-germs cleaners… ………etc)

Hospital facilities : Some of the big and expensive medical test machines (MRI, X-ray) can be substituted with alternative techniques using less expensive portable medical methods.

Staff : The government has to pay monthly salaries for a big number of nurses and other workers associated with the hospital (security, cleaners, ….etc).

In the case of diverting to portable medical devices, the only area where governments have to spend money in is the research centres to encourage more and more research on portable medical devices. The government doesn’t have to purchase these portable devices because they will be distributed in the market, and eventually the public has to purchase them as a substitute for hospital testing and hospital health checks.

3) A need for the immediate detection of a life-threatening disease: Excessive research on these devices can be a promising solution for diseases which has no cure, where the device can detect the basic symptoms of the disease and warn the user before the disease is incurable (eg. cancer).

4) A need for acquiring a business image: General-health measurement devices are scarce products. Even the specialised portable devices are scarce too, to some extent. In the past, mobile phones have existed but they had no popularity, they started becoming popular only in the last 10 years. Mobile phones have acquired a strong business image through these last 10 years. Similarly, medical portable devices at the present have a weak business image, although they are more important than mobile phones. Because watches have a strong business image like mobile phones, the general health device should take the form and appearance of a watch or a mobile phone in order to gain maximum acceptability by the customer.
5) A need for a 24-hour monitoring and automation system: If general health measurement devices are to be found in the market they will provide very limited medical measurements, and they will not be of the monitoring type, they will usually be activated according to the user's need. It is important that a monitoring system should be incorporated in our product so that the device will continuously extract medical information from the body and take crucial decisions about the user's health accordingly.

6) The need for a non-invasive system: If no harmful detection rays are used, the non-invasive devices are always safer, faster, cleaner, more advanced, and easier to perform.

1.1.2 The Starting Point of The Project

To start the project, we will first design questionnaires to be answered by the elderly segment of the society (since they usually have more health problems than other ages, which makes them primary customers for the portable "general-health-measurement" products).This "questionnaire study" is the first step in the QFD design methodology called customer voice. The progress of this study is explained in chapter 4.

1.2 Aims and Objectives of the Study

1.2.1 Aims

To review and partially develop a health-monitoring wearable device which has the size and appearance of everyday worn watches.

1.2.2 Objectives

1) To understand the needs and requirements of personal health monitoring systems; and to review, recommend, and evaluate the existing non-invasive medical sensory systems (eg. infrared, EEG systems), through QFD matrixes.

2) To take numerous readings of blood pressure values at different times and situations (experiments) in order to understand the influence of certain factors on blood pressure.

3) To integrate and establish the design of the QFD selected sensory techniques, and to suggest conceptual designs of the watch which will describe the positional importance and locations of the medical systems with respect to the hand wrist.

4) To review, recommend, and select suitable miniaturising systems and suitable watch technologies which will serve the overall medical purpose of the product. (Embedded processor systems, convertible watch body, MEMS sensors, MEMS memory).

5) To complete the purpose of the QFD study, where the product is developed to be accepted and purchased by customers. Providing a business plan which will guarantee

the availability of the product's manufacturing costs and business capital, thus proving the financial possibility of the project as well as the technical possibility.

6) To use the "harmonic design concept" and other design improvements, as additional design concepts to the QFD methodology; and to design the key components as an illustration of the possibility of manufacturing the product.

1.3 Proposals and Accomplished Literature Proofs

1.3.1 A Non-invasive Medical System with an EEG System

The following MEMS sensory systems are proposed to be integrated in a single cm range "main sensor". The MEMS sub-sensors of the main sensor include: (IR body temperature reading; IR Oxygen / CO2 level measurement system; IR blood density level system; A contact blood pressure sensor; A ribbon to keep the sensor in proper position. That is, the IR systems will measure and detect oxygen level, CO2 level, blood density, and body heat.

The conceptual design (proposed in chapter 5) describes the alignment of the IR system and piezoelectric MEMS system with the wrist, enabling various measurements and detections, but it doesn't emphasise on or specify the various detailed components or features of these MEMS systems.

The product is made out of a watch and head-mounted headphones convertible system. (Head -mounted headphones can become a watch and vice versa).The product integrates an EEG (Electroencephalogram) system which has MEMS dry electrodes inside the headphone body of the EEG for brainwave detection.

1.3.2 Experiments to Eliminate BP-changing-factors

The project proposes that the difference in BP values exerted by the "BP-changing-factors" will be used by the product embedded processor system (stored in the memory) to be compensated at certain times when measurement occurs (when these factors arises like hunger, eating, or walking). BP automation sensory systems that completes the role of the experiments (chapter 5), will be selected. In addition, a processor will combine different detections of different sensors simultaneously, to determine certain postures or situations that the user will experience (Eg. When the accelerometer and gyroscope don't show any movement signal for more than 20 min this means that the user is sleeping).

1.3.3 A Product Development Proposal "Functional-Area-Implementation" ; and a "Further developed product" Proposal

The introduction of a "Backward feature synthesis method". An added improvement to what is called "Conjoint Analysis technique (marketing) or, an added improvement to the QFD methodology (Engineering). Hint: Both QFD and conjoint analysis use customer voice to synthesise product features. The technique states that the space of the product will be divided in proportion of importance (the most important requirement takes the largest square area of the product and the least important takes the smallest.)

On the other hand, the product can be further developed by adding minor features(MEMS screen projector) to become a head-mounted portable extremely light weight computer system, that projects its VDU on surfaces (look at Appendix A or Future work in chapter 7). The future product consists of : (A head-mounted computer, A Non-invasive medical system, A mini-projector system, An EEG/BCI device(BCI=Brain Computer Interface),…………..all worn on the head and included at the same time. The product also provide the service of a marketing method (a Brainwave "Segment-origin" detection method p218-228), which detects or approaches common product preferences among a whole society made out of millions of people, to discover or identify a single product that can be purchased by those millions of people at the same time, generating endless profits (look at Appendix A , chapter 7 : Tele-marketing research p218-228). The project suggests an "automated-advertisement" concept watched by people on TV or on the internet pages, as a new concept of advertisements that is linked to the EEG technology.

1.4 Summary

The project will review and develop the design of the personal health monitoring system. The personal health monitoring system (watch-headphone product) will be partially designed using proEngineer software. Most of the device will be designed to show how the final product will eventually look like. The various devices selected to be part of the product (embedded processor) are proven to fit inside the system, both, when the device is worn as a watch and when it is converted as a headphone system. The EEG technology used in the product will allow the user to scan his body of specific pre-selected diseases or health problems. As the EEG physical disease research grows wider, more diseases could be upgraded to our system, increasing the limitations of our health monitoring system. The product uses a dry electrode MEMS sensor technology, which means that the scalp and hair of the user may not be covered with the electron-conductive-gel that is usually used in various EEG experiments. There will be special emphasis on blood pressure experiments that will enhance the automation of a "watch-headphone product", and also special emphasis on the implementation of nanotechnology in the product to make the product as small as possible. Examples of the MEMS types reviewed in this study are: Computer memory MEMS, sensory MEMS, and electrode MEMS and microphone MEMS.

Advanced watch literature is included in the study to search for any advanced systems that might enhance the capabilities of our medical product.

The following chapter to come (Chapters 2) is about the literature of the followed QFD methodology and the non-invasive medical measurement methods (health measurement systems, blood particles and blood substances detection systems). Advanced watch systems are reviewed too, even if these systems have features which are not medical, for it might be added to our medical watch , if necessary, to support the overall medical aim of the product (e.g. The processor of advanced non-medical watches can process health measurements of a medical watch).

Chapter 2 : Literature Review

2.1 Introduction

In this chapter, we are going to review many of the non-invasive medical techniques, devices, and sensors that can be added to our convertible watch-headphone product; plus other technologies like nano storage components and the methodology of the QFD study.

Doctors and health professionals use four standard body signs to assess a patient's status, these are called vital signs:

1. Temperature.
2. Pulse rate.
3. Blood pressure.
4. Respiratory rate.

These vital signs are covered in our watch-product, except for the measurement of the respiratory rate, because the wrist is far from the respiratory or lungs area of the body. The respiratory rate information might be measured in the future developments of this product, by detecting a sort of brainwave signalling from the users scalp that resembles respiratory speeds or rhythms.

There are many QFD matrixes that can be included for the evaluation and analysis of our product. The QFD study has a weighing system (Importance Weight) that is used excessively in this project to differentiate or filter the extremely important components and features with the less important and unimportant components.
In this chapter, a lot of reviewing of miniaturisation and nanotechnology is going to be conducted. The presence of nanotechnology in our product is vital.

Nanotechnology strongly supports the first 5 customer voice requirements that are shown below and in ch.3:

1-Solutions for the “old age” problems.
2- Multi-health-measuring design/system.
3- Accuracy of readings.
4- Easy to use.
5- Design ingenuity.

Nanotechnology makes the product more practical, lighter in weight, and smaller in size , which is a big need for the elderly people , and other segments as well. Because nanotechnology is made out of extremely small devices, there will be a lot of space for many systems to be combined together in a relatively small unit of the product surface (eg 1 cm). Therefore, nanotechnology plays a vital role in the integration of many systems in one small device e.g. multi-health systems. On the other hand, adding small devices (MEMS) to a system increases the sensitivity and accuracy of that system.

As automations are concerned, applying automation to a product is more possible using miniaturised processors and sensors, especially if the product is small in size. Therefore, nanotechnology will allow more and more products to be automated and it allows products to be more advanced too, thus, making life easier for the user.

2.2 Blood Pressure Definition and BP Measurements

Definition:

High blood pressure (hypertension) is a disease that is common among old-aged people, which arises from the unnatural contraction of the capillaries of the patient. The main cause of these contractions is still unknown. High blood pressure is not regarded as a life threatening disease, and is categorised with diseases of similar nature like diabetes and cholesterol problems.

Systolic pressure: The highest pressure in the beginning of the pump where the blood is driven away from the heart into the arteries.

Diastolic pressure: The opposite of systolic, where the blood fills the heart chambers due to the relaxation of the heart muscles.

Hypotension and hypertension :

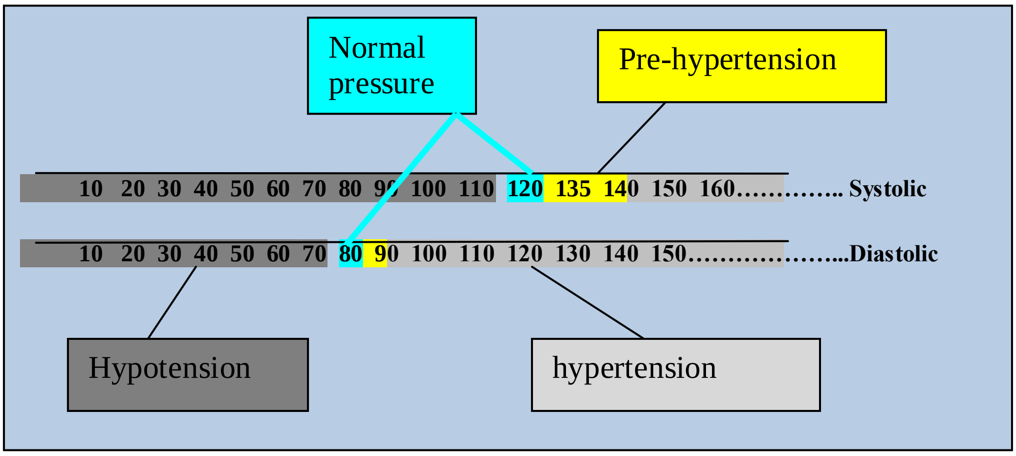


Fig. 2.2a Normal blood pressure, hypertension, and hypotension.

The Resonance Oscillometric Technique (inflatable devices) :

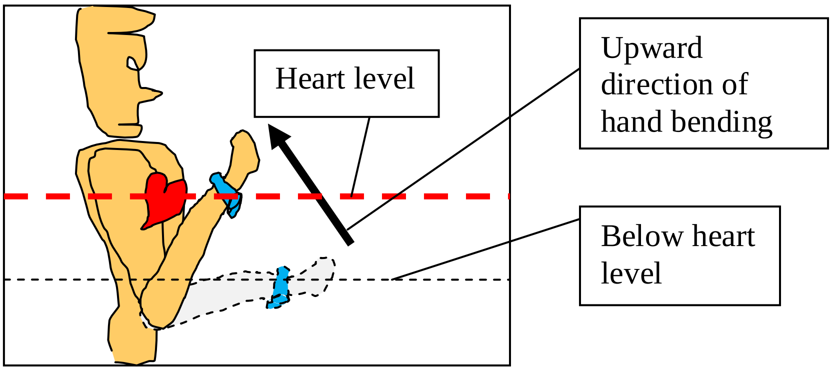


Fig. 2.2b A BP measurement posture.

This technique depends on the resonance of frequencies. When the patient experiences high blood pressure, blood flowing inside his arteries will have a specific vibrational frequency value caused by the compressed blood inside the walls of arteries. Ascending and artificial values of vibrations can be generated when a device pumps air around the wrist squeezing it. As the squeezing around the wrist increases, the device will have an acoustic sensor that is capable of detecting a resonance sound that evolves only when the artificial vibrational frequencies of the device will be equal to the natural vibrational frequencies of the blood pressure. When this special resonance sound is detected (korotkoff sound)the device stops any further squeezing and registers the last squeezing force which is usually proportional to the BP value, thus BP at this particular force is calculated which is equal to the patient's BP value. The systolic value is determined when the sound starts to appear and the diastolic is determined as the sound starts to fade away. Prior the advancement of sensor technologies the doctor used a stereoscope situated on the arm skin to listen to the unique resonance sound.

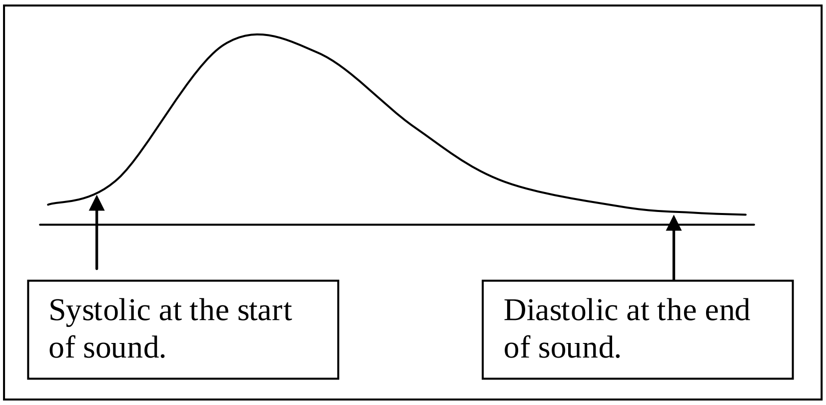


Fig .2.2c   The start and end of the korotkoff sounds.

The MEMS Displacement Technique (contact piezoelectric):

This is the modern technique of blood pressure (BP) measurement, which depends on measuring the distance of the push towards the skin surface, caused by the artery when inflated with blood. Modern sensors can also measure the vibration frequency of blood flowing inside arteries simply by the attachment of extremely sensitive MEMS vibrational skin-contact accelerometers situated above the skin on top of the wrist-artery and on top of the wrist-vein.

The Ultrasonic (ULT.SO) Reflectance Technique:

This is also a modern technique in BP measurement. The intensity of ultrasonic waves bombarding an artery with high pressure will vary if compared to the intensity of the waves hitting an artery with normal pressure. Thus, proportionality is established. The waves entering the flesh will reflect back off the surface of the artery and are sensed by a receiver.

Blood "speed/density" Rules :

Blood speed BS is inversely proportional to blood pressure, if and only if, blood density is constant ; Increasing blood density will decrease blood speed.

2.3 Relationship Between BP Value And Stenoses (Contraction of capillary walls)

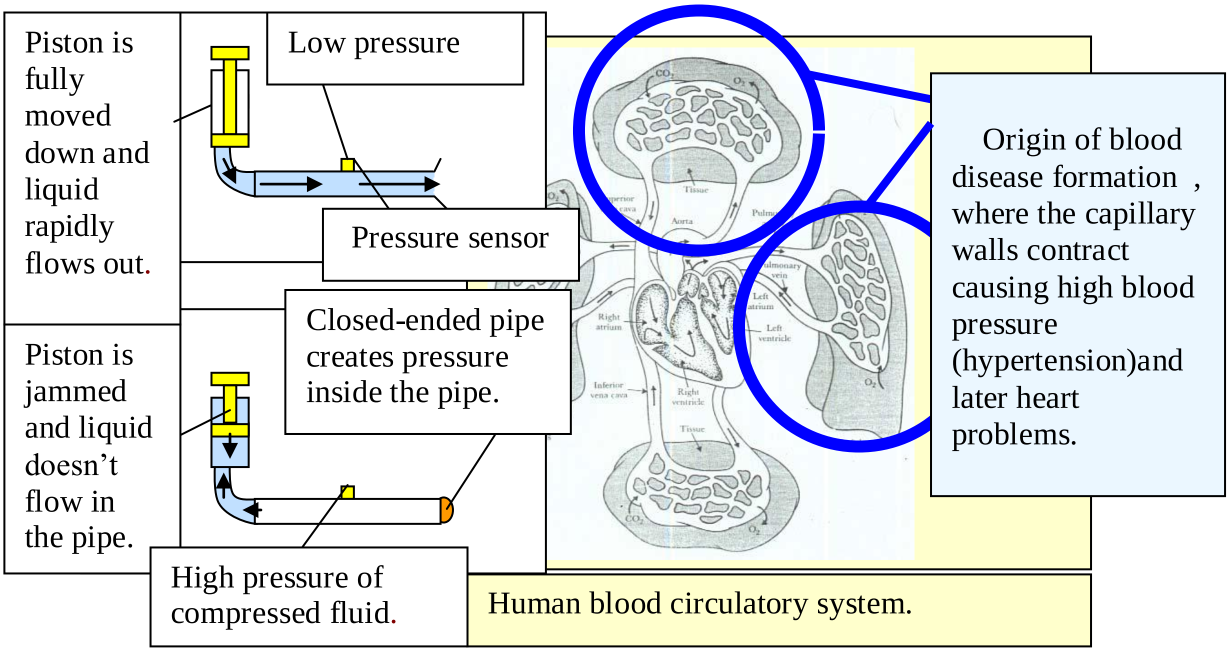


Fig. 2.3 Stenosis compresses blood in capillaries. [2]

<u>The Conclusion of This Experiment Is As Follows:</u>

Closed systems generate high pressures when liquid is pumped into it. In the case of hypertension (high blood pressure), the walls of capillaries contracts which makes the system a semi-closed system, thus elevating BP to hazardous values. The jammed piston shows what happens to the heart of a patient having BP problems. This patient might easily get heart problems.

This is a very simple demonstrative experiment that we might encounter in everyday life about the accumulation of pressure in a closed system. (e.g. A garden hose will get inflated and hardened if a knot is formed at some point along the hose.)

2.4 Advanced “Normal size” Blood Pressure Watches

Blood-Pressure Watches (Contact –Sensor):

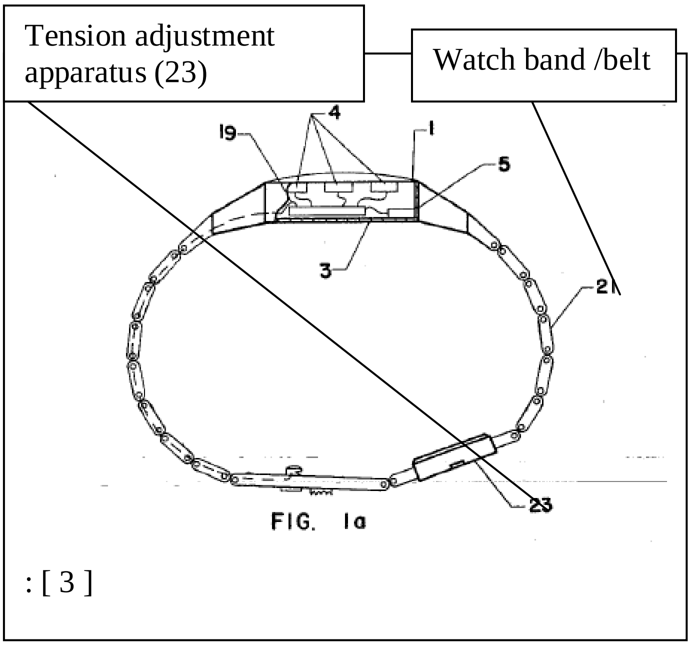


Fig. 2.4a   Advanced contact BP sensory watch.

The above watch (Fig 2.4a) translates the force exerted on the vein walls of the wrist to a contact piezoelectric sensor attached on watch strip (always in contact with the skin of the wrist).The selected contact sensor for this watch can sense the deep force that hardens the tissue beneath the sensor which pushes up the skin. This point is very vital, since that if a wrong piezoelectric sensor is used, the skin tension force might be measured instead of the blood pressure force, which pushes up the skin. The skin tension force might be generated from various hand and wrist movements.

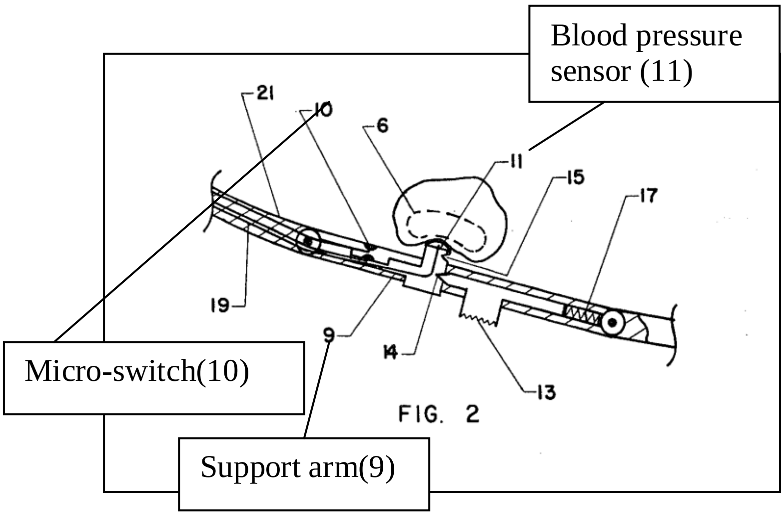


Fig. 2.4.b   Advanced contact BP sensory system.

This sensory system (Fig. 2.4b - above , part of the main watch Fig. 2.4a) has a mechanical switch which will eject or retrieve the BP sensor(11) in and out of the watch, depending if the user wants to measure his BP or not. Also, an adjusting component (23)-(2.4a) is used to control the length and tension of the watch belt (21), this adjustment is extremely important for the threshold force calibration of the BP contact sensor. The response of the skin to blood pressure is variable from person to person, since that the effect of blood pressure on human skin will be much weaker on fat people than skinny people. (The wrist vein of fat people will be deeply buried under layers of fat).

2.5 Other Types of Non-invasive General Health Sensors

<u>Piezoelectric Vibration Sensor:</u> [13]

The sensor will use a vibrating material to create proportionality between the magnitude of BP and the frequency of vibrations of the vein. This material is very sensitive vibrations and will vibrate itself responding to the vigorous vibrations of blood flow as blood squeezes itself in veins. The oscillations of the material will be transferred to electric current as in the case of all piezoelectric sensors.

Nanotechnology sensors: [44]

The most accurate of all the oscillatory blood-pressure measurement techniques ; Since that the sensors are usually manufactured to the micro level(MEMS) ,where the sensors are extremely sensitive to any change in blood pressure due to its tiny size (the small force and displacement from beneath the skin means a huge displacement for a micro or nano sensor). The technology was first applied on disposable blood-pressure sensors.

Mechanical sensors : [6]

These sensors will use a mechanical system (usually a spring) to reflect a proportionality between the magnitude of the pressure and the magnitude a displacement change that will occur in the mechanical system and which will usually be converted into electricity. This system is used in contact blood pressure sensors.

Ultrasonic transducers as a body sensor: [11]

Are used a lot in the medical field (mostly as a visual technique), waves are continuously hitting an organ and reflecting back until a real time image is formed. The advantage of this technique over other methods is that the ultrasonic waves can reach deeply hidden body organs that need to be photographed or monitored.

Acoustic emission: [14], [15]

Acoustic Emission AE is a technology that detects stresses and strains of materials. AE can read the pressure of a system by reading how much stress can it exert on the container. The AE emitted by a system is read by an AE sensor that is piezoelectric in nature, where these signals are converted into electric signals via this sensor. The frequency range of acoustic emission is approximately between 100 KHz to 1 MHz.

2.6 Piezoelectric Sensors and Accelerometer sensors For Blood Pressure Measurement

Electrodes of the accelerometer collect charges. Wires transmit the charge to a signal conditioner that may be remote or built into the accelerometer. Sensors containing built-in signal conditioners are classified as Integrated Electronics Piezoelectric (IEPE) or voltage mode; charge mode sensors require external or remote signal conditioning. Once the charge is conditioned by the signal conditioning electronics, the signal is available for display, recording, analysis, or control. [4]

Recommendation:

The (IEPE) technology mentioned in the above paragraph is recommended to be selected, to be part of the piezoelectric system of our watch. Signal conditioning will give the sensor more selectivity of accepting or ignoring certain displacement forces, vibrational forces, or any random movements that can affect the skin in any way. Thus, IEPE technology will give the watch more accuracy since that it will allow it to differentiate between extraneous skin movements and BP originated skin movements. Accuracy is the third most important requirement of the QFD requirements.

2.6.1 Accelerometer Voltage And Calibration

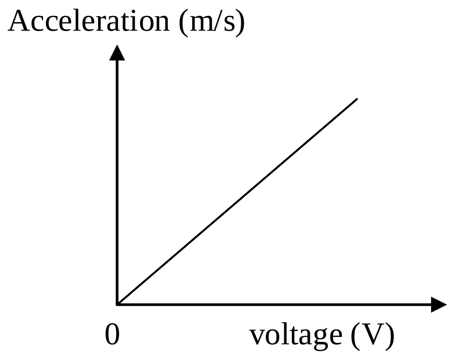
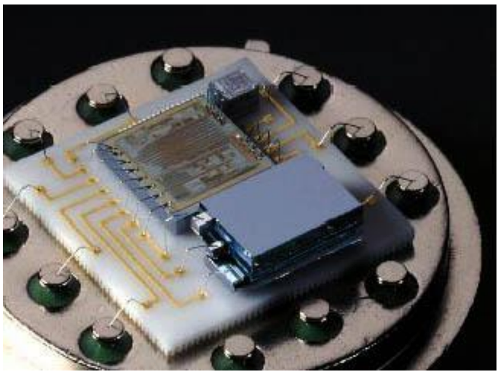


Fig.2.6.1 a Acceleration-voltage proportionality graph.

Accelerometers can be calibrated according to need. Specialised machines can control and change the sensitivity of the accelerometer or the magnitude of the frequency by which the device is stimulated.



http://www.wtec.org/loyola/mcc/mems_eu/Pages/Chapter-5.html)

Fig. 2.6.1b CSEM 6100 Accelerometer with interface circuitry. [5], [6]

Accelerometer Types:

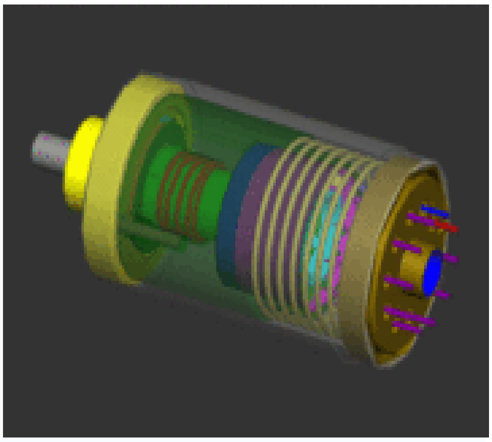
1) Integrated Accelerometer: Mainly used for sensing vibrations.

2) Strain Gauge accelerometer or (piezoresistive): Specialised in measuring constant-acceleration.

3) Servo accelerometer: Very accurate and are suitable for measuring angular acceleration.

4) MEMS shear accelerometers: (Explained below).

2.6.2 MEMS Shear Accelerometers



(http://en.wikipedia.org/wiki/Image:
Accel.gif)

Fig. 2.6.2 A depiction of an accelerometer (MEMS) designed at Sandia National Laboratories.

A problem that might threaten the accuracy of such a device is an extra force that might be exerted by the seismic mass (changes force into charge), This extra force originates from the weight of the Seismic mass itself. In other words, the seismic mass can trigger itself. This might give inaccurate or wrong readings when accelerometers are on a cm range. Fortunately, this problem is solved, where it is found by the numerous experiments made that the mass will exert no extra force on the crystal when the sensor is diminished to a certain micro size. Therefore, a shear accelerometer will gain practicality (easy to move from place to place) and low cost (since that is small in size), and at the same time its accuracy will be improved. [7]

2.6.3 A CMOS MEMS Piezoelectric Skin-contact BP Sensor.

A CMOS integrated pressure sensor is manufactured using post-processing steps. The integrated readout circuitry achieves a resolution of 12bit at a conversion rate of 1kS/s.

This device, which was fabricated in 2005, can be used as a 24 hour pressure monitor.

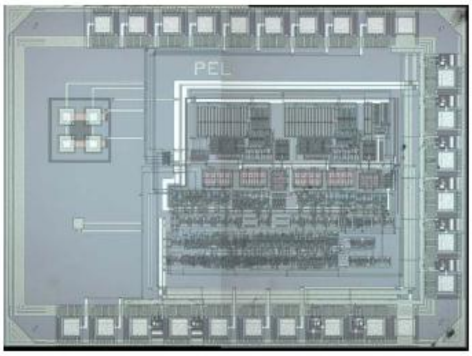


Fig. 2.6.3 a CMOS Integration inside a sensor. [8]

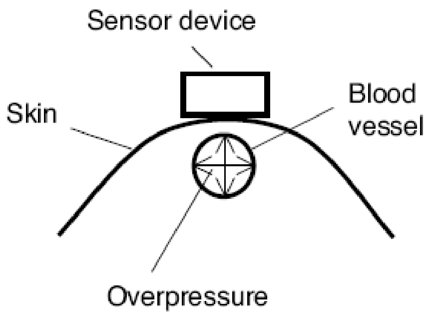


Fig. 2.6.3 b Piezoelectric MEMS(mm range) Accelerometer sensors.

Recommendation:

This milli-range piezoelectric sensor (Fig. 2.6.3b) is highly recommended to be used as a BP portable system. Thus, using this device, the manufacturing of a blood-pressure watch, with a normal size, will be possible. This special watch will not be entirely similar to normal watches, since that the sensor should always be in contact with the wrist skin. (Possibility of the product : The product is available in the market.)

Accelerometer , pressure, and force blood-pressure sensors :

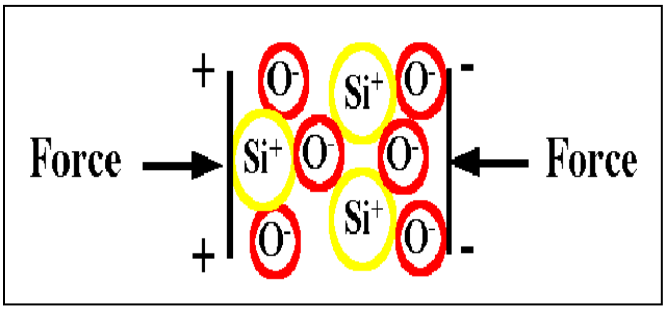
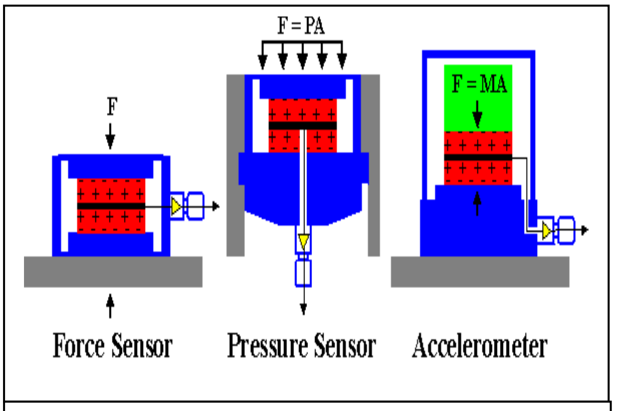


Fig. 2.6.3c Rearrangement of charged particles.

Piezoelectricity is formed when the charges of the piezoelectric substance experiences a rearrangement of locations due to the exertion of an exterior force. This rearrangement will usually push similar charges on each side, stimulating the generation of an electric current. Types of piezoelectric materials are : Quartz, man-made polycrystalline, and piezoceramics.



(http://www.pcb.com/techsupport/tech_gen.php)

Fig.2.6.3d Types of piezoelectric sensors. [9]

Those are the major types of piezoelectric sensors. Accelerometers measures motion changes which occurs in a direction compatible with the design of the sensor. Pressure sensors measures pressure that is exerted on the sensor by means of a specialised surface or a diaphragm, that resembles the area factor of the equation F=PA, where A is the area under pressure. A specialised component for the area is established hear to allow the fluid causing the pressure to even up on this surface where its calculation would be possible. Finally, force sensors are particularly similar to pressure sensors except for the surface component, since that the area in the case of a force sensor is determined by the external force causing the force reading. [10]

Pressure, force, and acceleration sensors all have piezoelectric bases in common, that is, the method of detection has or uses piezoelectric materials.

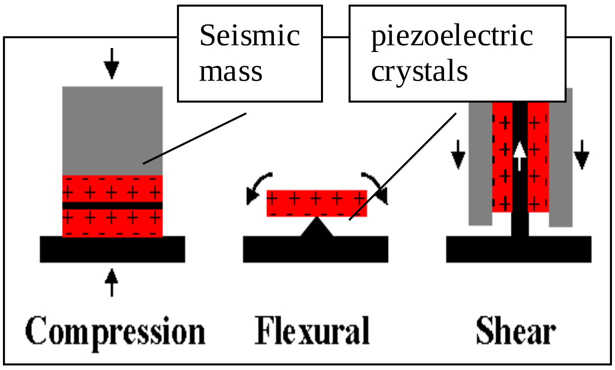


Fig.2.6.3e Types of configurations.

Shear Mode:

The structure of the sensor is made in a way that will allow the seismic mass to be extremely sensitive to the slightest motion and it gives it more freedom to be used in all sorts of applications, in addition to this, it is not affected by the surrounding temperature.

The preload ring aids in the linearity of the system.

Flexural Mode:

This device is most appropriate for applications where low frequency is used and where the change can take hours and hours of time (unlike other types of high frequency where the change has to occur quickly to be understood by the device) .This long change can be most suitable for construction engineering applications where the equilibrium with reference to gravity is inspected, or how perpendicular are objects to each other.

This device is accurate and cheap.

Compression Mode:

Compression accelerometers are used for high frequency pressure sensing or any selected application where high frequency is used. This device has limited applications and low reliability. It is divided into 3 types: (inverted, upright, isolated)

2.7 Acoustic Emission / or Ultrasonic Sensor Technology

2.7.1 Ultrasonic Technology and Ultrasonography

Fig.2.7.1a Ultrasonography transducer. [11]

Ultrasonic technologies are widely used in medicine for both diagnosis and treatment. Ultrasonography (producing visual images through ultrasonic rays) can show real-time videos of : blood vessels, kidneys, liver, brain, main arteries and capillaries, the heart, bladder, tendons, muscles, lungs, blood particles, and foreign bodies.
The Expert engineers of the technology can modify frequencies of propagation of the ultrasonic waves so that it can penetrate deep in the body, reaching nearly for any organ. The size of the Ultrasonography transducer is as big as a shaving machine (shown in above Fig.). This device cannot be part of the portable watch since that it is extremely large.

Miniaturizing this “Ultrasonography transducer” will lead to the extremely useful development of portable diagnosing systems.

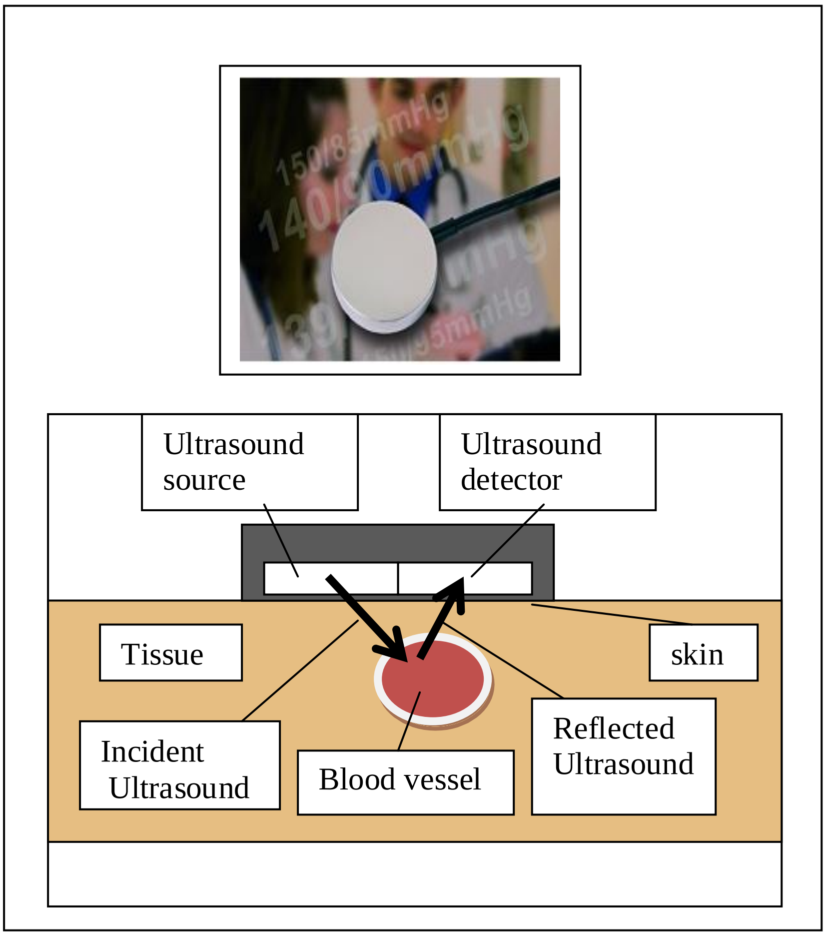


Fig.2.7.1b Diagram and photo of Ultrasonic blood pressure sensor. [11]

The above photo shows a non-invasive and ultrasonic blood pressure sensor of a diameter between 2 and 3 cm. The ultrasonic waves penetrate the arm where a receiver sensor absorbs the changed ultrasonic waves at the other side of the arm. The thickness of the emitted ultrasonic waves are minimised by how much blood is pressurised, thus BP can be measured. The only disadvantage of this system is the relatively large size which won’t allow it to be part of a normal size watch. If there is a possibility for miniaturising this sensor it will form a perfect sensor to be part of the medical watch device. [12]

2.7.2 Types of AE Sensors

There are different AE sensors of different sizes, shapes, frequencies, and temperatures of operation.

1) General purpose sensor.
Description and Application: Used for most acoustic emission applications.

2) Wideband sensor.
Description and Application: Very accurate.

3) Miniaturised sensor.
Description and Application: Very small sensors (MEMS), 2mm.

4) High temperature tolerance sensor.

Description and Application: Can operate at temperatures up to 1000ºF (540C), can be used directly on structure surfaces, used in AE aerospace engine monitoring applications.

5) Underwater sensor.
Description and Application: It is used underwater (waterproof). It can be constructed in water containers, ships, liquid pipes.

6) Low frequency sensor.
Description and Application : For geotechnical and leak detection applications where long distance detection can be applied.

Recommendation:

Possibility for blood pressure detection: AE pressure sensors are available in the market (contact and non-contact), unfortunately they are rarely used as BP sensors.

Only “Acoustic sensors” (different from “Acoustic Emission sensors”) are applied to inflatable wrist-devices detecting the extremely low sound of blood flow as a substitute for the doctor’s ear.

The Difference between Acoustic sensors and AE sensors :

Acoustic Emission sensors will detect the sound waves that cannot be heard by the human being which is usually generated from materials under stress , while acoustic sensors will detect sound that can be heard by people.

Specialised AE Sensors :

1) Fluid Pressure AE sensors.

2) Unidirectional type AE sensor.

3) Differential Type AE sensor.

4) MEMS Type AE sensor.

5) MEMS Airborne (Non- contact) AE sensor.

2.7.3 Fluid Pressure AE Sensors

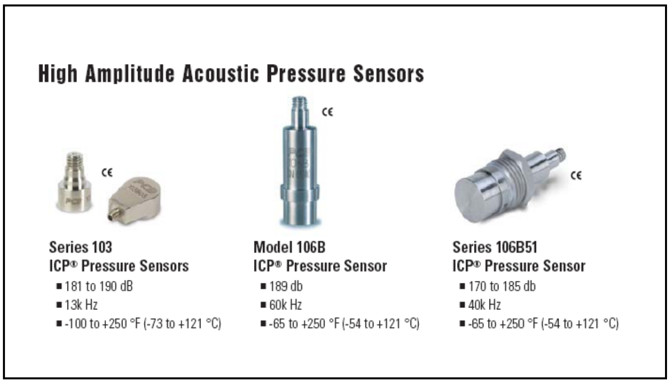


Fig. 2.7.3 Fluids pressure AE sensor(cm range). [13]

The AE watch sensor should have the structure of a fluid Pressure Sensing types (water pipes and containers, petrol pipes, pressurised liquid containers….).

How can this feature help in designing the watch or the watch AE sensor?

This AE sensor attached to the watch is supposed to measure the pressure inside the veins which contain liquid blood. These sensors (Fig. 2.7.3: above) are made for the continuous monitoring of gases and liquids high amplitude pressures. Although the pressure inside veins is not high, the same structure of these sensors can be used for the watch but with slight changes so that it can measure low levels of pressure.

2.7.4 Unidirectional Type AE Sensor

The unidirectional Acoustic Emission sensor is specialised for the detection of monitored pipes which are more important than the nearby ones. The device is designed in a way that surrounding signals from other pipes are rejected .The device can also identify the source it should be monitoring even if the source will change its position.

How can this feature help in designing the watch?

This device is ideal for blood pressure monitoring since that the patient in certain situations might be present in a location rich in acoustic activity that might disturb the detection of the watch sensor (background noise). If this device will be used, the patients can freely go to locations high in AE activities and still blood monitoring will not be affected.

Parameters of the unidirectional type [14] :

Model	:	09240
Dimensions	:	38x38 mm.
Weight	:	300 g
Operating temp.	:	- 65 to 121 C

Peak sensitivity : 43 V/ (m/s)

Frequency range : 250-625 KHz

2.7.5 Differential Type AE Sensor

This type of AE sensors has a very sensitive level of detection of low acoustic emission signals. In addition to this, the sensor can neglect or minimize background acoustic emission activity to a very low level so that the desired AE source will be clearer and filtered from the accompanying acoustic activity.

<u>How can this feature help in designing the watch?</u>

Low –AE detection in the case of BP measurement or even vein–pressure measurement is extremely essential. The acoustic emission signal emitted by the wrist vein is supposed to be relatively weak, if it should be compared with signals emitted from factory pipes.

Parameters of the differential type [15]:

Model : micro30D

Dimensions : 10x12 mm.

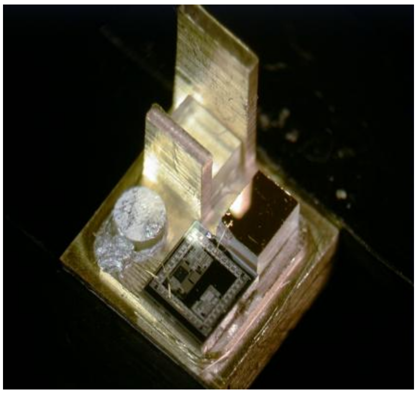
Weight : ---------

Operating temp. : - 65 to 177 C

Peak sensitivity : 65 V/ (m/s)

Frequency range : 100-600 KHz

2.7.6 MEMS Type AE Sensor



(http://www.ece.umn.edu/groups/mems/acoustic_emission.html)

Fig.2.7.6 Integrated AE sensor (mm range).

The basic advantage of miniaturising AE sensors is the ability to combine several types in one body without getting a big and bulky sensor, or even combining the sensors using CMOS technology. If the sensors are not made small, then they will be large and heavy, making the measurement process unpractical or impossible to be fitted in a wrist -watch . On the other hand, MEMS sensors are cheap in price, so, even if several MEMs devices are attached together on the watch, this won't affect the price of watch.

How can this feature help in designing the watch?

In the case of vein-pressure measurement by means of an advanced watch, miniaturisation is a must, since that the diameter of the wrist-veins is small.

Parameters of the MEMS type [16]:

Model	:	------------
Dimensions	:	5x4 mm.
Weight	:	1 g

Operating temp. : ---------------
Peak sensitivity : highly sensitive
Frequency range : 100-600 KHz

2.7.7 Airborne Non- contact AE Sensor

This type of AE detection has the advantage of a non-contact method of detection.

<u>How can this feature help in designing the watch?</u>

If there is a possibility of miniaturizing this sensor, it can be attached to the watch frame around the wrist vessels area to detect the pressure in a non-contact way <u>(so as not to restrict the patients to keep the frame tight to his wrist).</u>

Parameters of the airborne type:

Model : AM21
Dimensions : 29 x 51mm .
Weight : 81 g
Operating temp. : 0-70 C
Peak sensitivity : 3 V/ (m/s)
Frequency range : 20-50 KHz

Recommendation:

The non-contact acoustic emission technique is recommended (only if proven to be able to measure BP) to be used as the major sensing technique of the watch for 2 reasons.

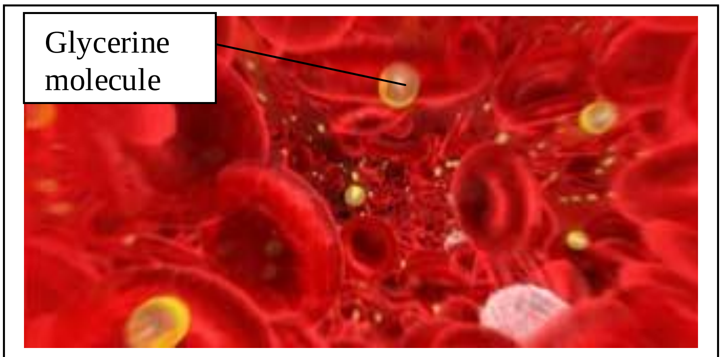
1) Very practical since that it gives freedom and comfort for the person wearing the watch.

2) It allows the introduction of cholesterol detection (acoustic methods) through the vein. (Cholesterol detection is regarded as an example of <u>multi –health measurement</u> service, the second most important factor in the requirements table.)

<u>Possibility of the product</u> : Although it is logically obvious that AE can measure blood pressure by measuring how much its containing vein or artery is hardened, this technique was never used. There is no literature evidence that a non –contact AE method or sensor is used for BP measurement.

2.7.8 AE or Ultrasonic Detection (AE/ULT.SO) Of Blood Constituents

<u>Literature evidences that Cholesterol and blood Objects can be detected with AE/ULT.SO [17]:</u>

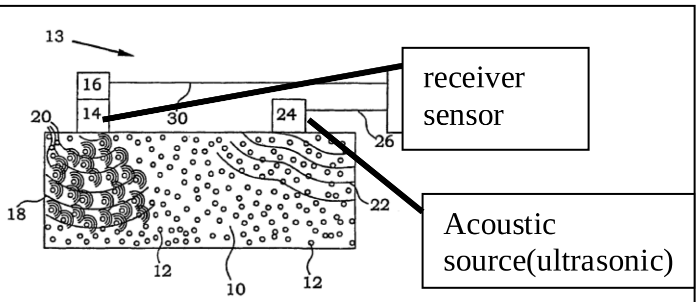


http://www.cardioconnection.org/images/dyslipidemia/subPages/d3-3.jpg

Fig. 2.7.8a Blood stream particles and cells (nano-micro range).

There are AE/ULT.SO devices which are not yet in the market, but has been directly researched through research papers for blood pressure measurement and other non-invasive health measurements, or has been indirectly researched through similar experiments, situations, or research papers, will form a logical proof that the devices can be applied on blood pressure measurement and health measurements at the same time; If and only if, these systems are to work if miniaturised.

AE and ULT.SO sensors can measure how compact a material is or how loose it is. That is, it can measure the magnitude of strain experienced by a material, which implies that AE and ULT.SO can be used for BP measurement by sensing how much vein walls are stretched as a result of BP on the inner walls.



(http://www.freepatentsonline.com/20040006409.pdf)

Fig. 2.7.8b Active acoustic spectroscopy in factories (cm range).

Literature proves that ULT.SO can detect solid particles inside liquid or multi-phase liquid inside liquid.

An Acoustic source is attached to a liquid container which contains emulsions (Fig. 2.7.8b). The source emits acoustic signals by means of a pressure pulser or a vibrational pulser which sends these waves through the container liquid. An acoustic receiver is waiting on the other side to detect theses acoustic waves. A different result interpreted by the receiver sensor (which is an ULT.SO sensor) resembles different nature, amount, size, and properties of the emulsions. The frequency of the signal cannot be more than 20 kHz. It is also proven that ULT.SO technology was able to detect minute organic cellulose particles and starch in water or other organic liquids.

This is a logical and literature proof that AE/ULT.SO is a good technique, but the AE method is used much less than the ULT.SO method in medical detections, this is why it will not be selected as part of our product systems.

Like the electromagnetic method, AE applications in the medical fields are minimal compared with infrared , optical methods , and ULT.SO, therefore selecting it as a basic sensory system can be a risk; Especially that its abilities in detecting glucose and cholesterol in the blood are not tested yet by any literature that we have any knowledge about.

Limitations of the possibility of AE/ULT.SO detection of blood emulsion, glucose, and cholesterol:

AE and ULT.SO devices can detect 3-dimensional vein shapes and forms (very similar to 3-dimen. blood particles) even if they are buried under flesh. [18]

ULT.SO can also detect hard particles in oil (sand particles) , thus , it might be possible for the same ULT.SO system to detect hard alien particles in the blood stream like germs , tiny stone-like particles that reaches the blood stream and cause illnesses; ULT.SO can also do blood inspection for any extraneous bodies that might be harmful to the human being. [19]

A feature that has to be added to our medical device is the detection of vein – stenoses (narrowing of vein walls). We should not forget that vein stenoses can be the primary cause of BP disease (hypertension) acquired by the elderly people. Therefore, detecting stenoses can be another way of detecting blood pressure, owing to the fact that BP (hypertension only) occurs when the artery and vein walls of the human body starts to experience stenoses.

The latest work on artery detection (mentioned in the above paragraphs about blood objects detection), is a medical device [20] used to detect 3-dimensional volumes of blood vessels, even that they are buried under the body flesh**,** which means that stenoses can be detectable. An array of contact-ULT.SO sensors can be used to detect the stenoses veins under the inspected area.

2.8 Infrared Sensors (non-contact) : Types of Infrared rays And Their Applications

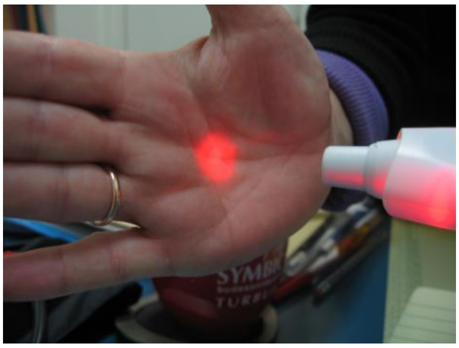


Fig. 2.8 Non-contact infrared Thermometer (cm range). [21]

To measure heat radiated from a surface (human hand) the D:S ratio has to be calculated. D:S means ratio of distance of emitted ray(from the LED to the surface) over the spot area that the ray forms on the surface (shown on the above photo: red spot).

Infrared rays can be divided into many types and used in many applications. Near-IR: is absorbed by water. Short wavelength-IR: has total water absorption. Mid wavelength-IR: applied in heat sensor technology. Long wavelength-IR: known as "thermal imaging technology", where hot objects only are versioned. [22]

Thermal detectors (photocathode) detect infrared radiation (not heat) which originates from hot objects. This Process is completely different from spectroscopy and from infrared thermograph. Spectroscopy is a method of detecting substances; IR thermograph means: using infrared technology as a sort of camera to watch the presence of heated and cold objects around us and it mainly uses "mid infrared rays".

Infrared spectroscopy can be used as a non-contact sensing method (like AE and ULT.S), which can even be more powerful than AE/ULT.SO since that it has the ability to select and detect particular substances from a collection, that is, it can be an excellent identification technology.

Therefore, it is very likely that this technology(infrared identification)should be used as part of a “ multi-health measuring device” ; A device that measures more than blood pressure, probably glucose level in blood or even cholesterol level(as requested by old age patients –QFD).

2.8.1 Pulse Oximeter

(http://en.wikipedia.org/wiki/Pulse_oximeter)

Fig. 2.8.1 A portable pulse oximeter (cm range).

A pulse oximeter measures oxygen level under the skin. Infrared rays pass through a thumb, penetrating it until it reaches a sensor on the opposite side. This sensor measures the portion of rays that manages to escape from the thumb barrier. Blood which is fully oxygenated will have a totally different reading from one which lacks oxygen, thus this is how oxygen is being measured.

2.8.2 Direct Probing and Reflectance Probing

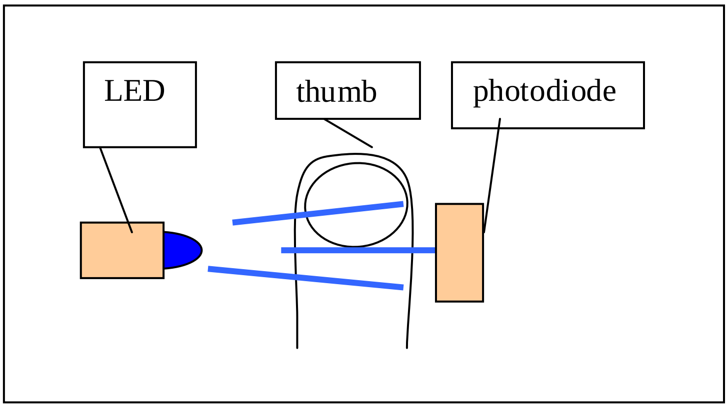


Fig. 2.8.2 Direct infrared probing method.

Using reflectance probing, IR detection of oxygenated blood will still be possible since that the IR ray will be reflected back (diffracted) after a partial penetration through the blood under the skin. [http://jp.hamamatsu.com/en/rd/technology /health/rdot.html]

2.9 Electromagnetic Methods

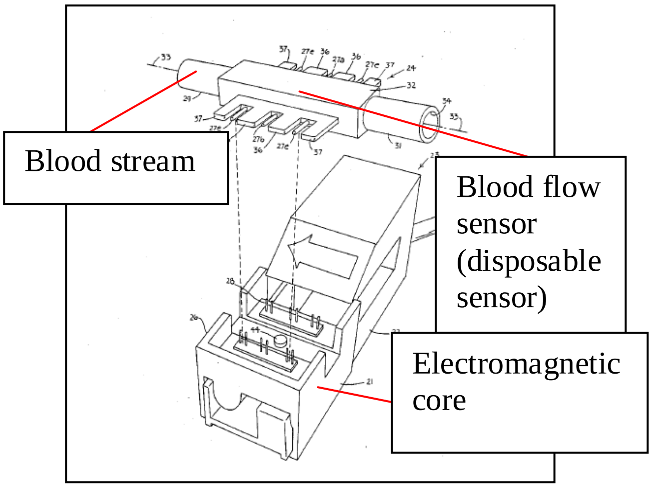


Fig. 2.9a Disposable and invasive electromagnetic BP sensor. [23]

This is the only literature found for measuring BP electromagnetically. This method is an invasive method, therefore it will be excluded from the evaluation scheme of the non-invasive medical measuring techniques, but the general electromagnetic technique <u>will still be evaluated</u> since that it is used at the present for a number of medical applications other than BP measurement.

<u>The Technique [24]:</u>

Since that haemoglobin particle in the blood contains iron molecules, the passage of blood stream containing iron through a wire coil will be similar to passing a conducting metal rod with your hand pushing it through a coil of wire with a magnetic field. This popular physics experiment induces current in the wire coil, which can be measured precisely by ammeters.

<u>Non-invasive Electromagnetic Glucose Measurement Devise :</u>

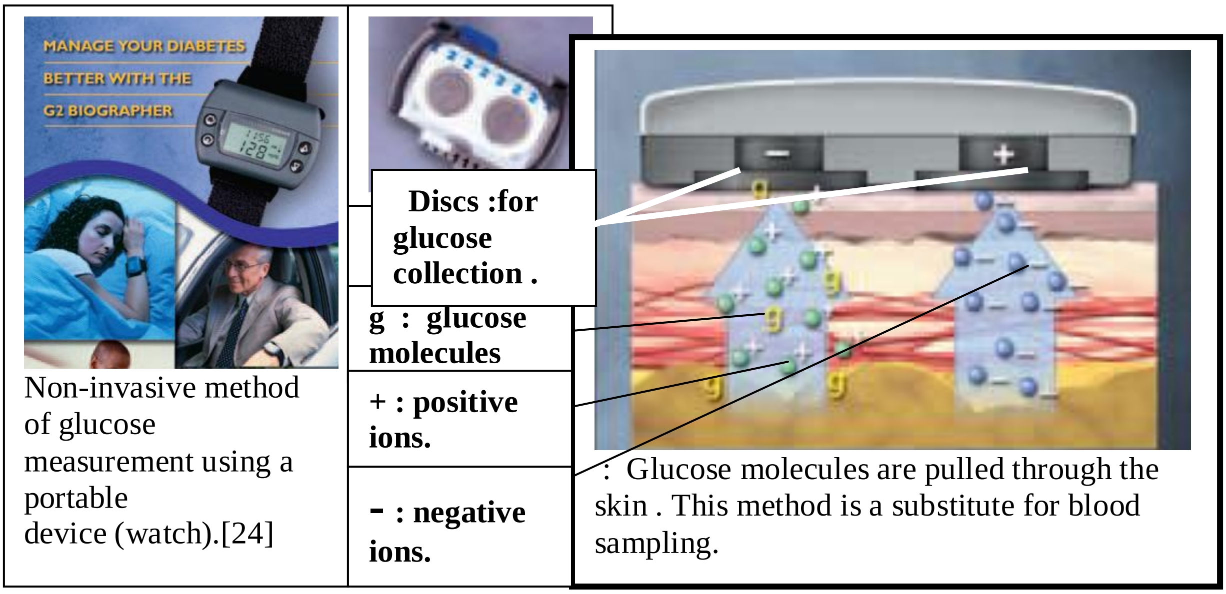


Fig. 2.9 b A glucose measurement skin-permeable Advanced Watch(California 2007).

The watch generates a low electric current at the surface of the skin; Since that glucose molecules have a positive charge they will slowly move upwards penetrating the skin(in 30 min). Then glucose will be collected in discs at the lower surface of the watch (the surface which is in contact with the skin). The watch will measure the glucose quantity by means of an electromagnetic sensor. [26], [27]

Recommendation (for G2 Biographer – up) :

This factor supports the QFD requirement No.1: solutions for "old age" problems. This technique eliminates the finger pinching for blood sampling which saves old people from a lot of pain, but unfortunately this watch has to be tight to the wrist so that the inner surface of the watch will have a firm contact with the skin for the glucose molecules penetration to occur smoothly from the blood stream to the skin, and finally to the watch discs. The tightness of the watch to the wrist makes it uncomfortable in wearing but it will always be better than pinching.

This technique is fairly recommended since that it supports the most important requirement of the QFD study.

2.10 Glucose and old-age -care Devices.

2.10.1 Recommendation: Wristband Transmitters

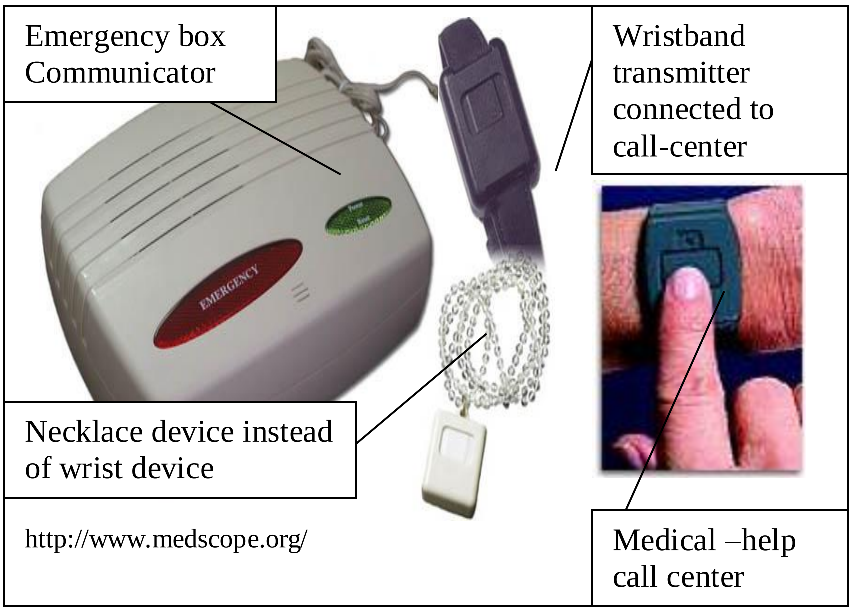
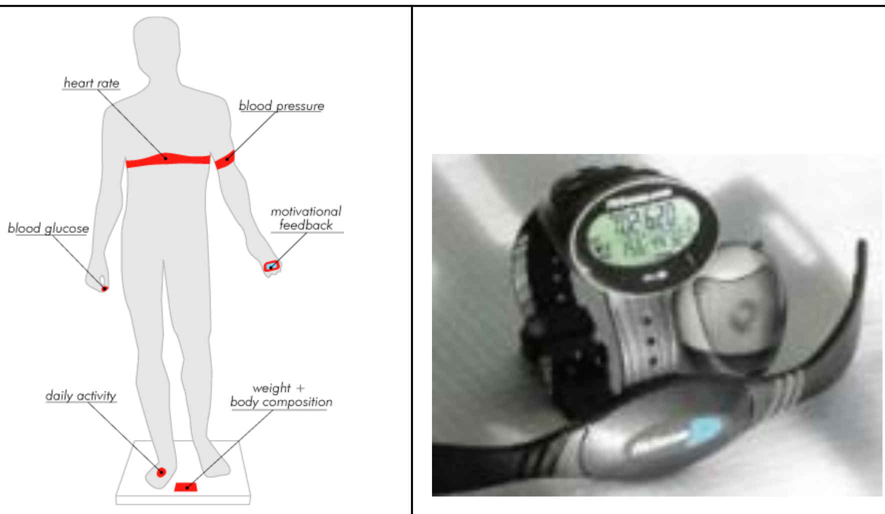


Fig. 2.10.1 Old-age-care devices.

These devices which are currently available in the market (for a monthly payment of 35 dollars) are extremely useful for old-age users since that it provides them instantaneous communication, vocal help, and provides advice; But it still not very useful for people with hearing problems. An added improvement to this system should be a headphone that is inseparable from the wrist device, and also no need for the big emergency communicator (white box - Fig. 2.10.1). The communicator is a stationery device that is placed inside the house to transfer the voice of the elderly and disabled people in a hands-free manner to the help-center, if they are to be in danger or cannot use their mobile phones. The basic problem concerning this “white box communicator”, is that it cannot be a help for old people with a weak hearing sense which is a very common problem among the elderly. While the old-age user is in danger the device might be far away from him, situated in a room different and far away from the accident place, this means that not only the user cannot hear the help-advice clearly but also he might not be able to hear it at all. This is why it is preferred to talk directly to the watch, or wrist–device instead of depending on a separate remote device (white- box communicator) that can be a help only when the distance conditions are perfect and when the user is inside the house since that it is not portable.

2.11 Multi-health Measurement Systems

2.11.1 Advanced Watch Multi-health Measurement System



: [28]

Fig. 2.11.1 Advanced medical monitoring watch.

This portable health system is a product of "FitSence Company". This watch has the following features, all in one watch: Weight management, body fat and weight management, blood pressure, blood glucose, health and wellness, Disease management.

Small sensors are distributed at different locations on the skin (5 main locations), the sensors send signals to the watch.

Recommendation:

This product is not very suitable for old people since that has low practicality and it is not easy to use, the sensors has to be situated in different places which means that the user has to take them off and put them on again regularly after having a shower. The device is not a comfortable one but it has a high ingenuity factor and it is highly advanced. Also, it is a perfect Multi –health measuring system.

2.11.2 EEG-form Multi-health Measurement System and monitoring

Recent research has proven that a considerable amount of physiological health status and physiological diseases could be spotted in its early stages with the FMRI technology.

Because the EEG device is an indication of such diseases, EEG technology is now regarded as an alternative hospital test to other tests like blood tests, radioactive rays tests that indicates illnesses, and measure biological quantification of the human body.[29]

2.11.3 Blood Sugar Level, Oxygen, And Carbon dioxide Level

The EEG can detect blood sugar level through the “signal identification technology” which is used nowadays for video games control or other laboratory or medical uses. A certain health problem affects certain parts of the brain, making them more active. This extra activity can be shown on the FMRI images especially if it is compared with the brain images before the health problems occur. A specific signal will be established for this “extra activity” in the brain. The established signal will be stored in the medical EEG memory, so that if the user will ever experience a health problem (high blood sugar), the device will warn the user that his blood sugar level has reached the dangerous levels. [30], [31] How are the disease signals detected?

The disease signal coming from the brain is compared (by means of a buffer) with a database of already stored disease signals in the EEG-headphones memory. Prior the signal comparison stage the signal is amplified and refined, and then, it is converted from its analogue state to a digital state. [32]

2.11.4 General Health Detection

Physiological stress is an extremely important health issue that might affect the human life and happiness, and productivity, and at the same time can be a cause for serious mental and biological diseases like depression and liability to infection. Detecting stress can at least inform the user that things are not going well, and that his body is experiencing stress, especially if it will be measured through a device which can specify the intensity of stress (normal stress, high stress). At this point, when the consumer is informed that he is being stressed out he can take more care with his health, knowing that for example, he should reduce the stressful work, solve social problems that might be the reason for the stress, or at least take a little bit more care with his health since that stress reduces the bodies immunity in fighting infections.

Work has been done on this topic in Nov 2007 (United States). The stress levels of a number of subjects have been measured to prove that physiological problems produce stress, and that this stress can be detected and imaged with the FMRI machine.

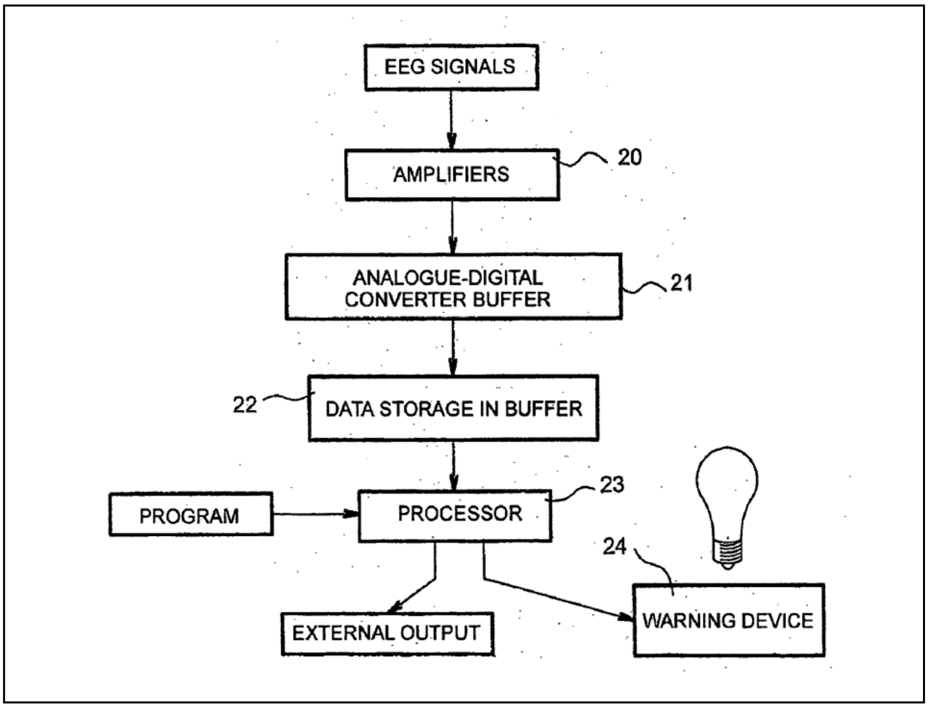


Fig. 2.11.4 An EEG processor with a user-warning Algorithm. [33]

Research has been made (Jan / 2006) on the prediction of disease in its early stages via a portable EEG device. The study measures the intensity and type of the disease using a database of brainwave images and a processor (Fig. 2.11.4) which identifies disease signals as they start small and grow large indicating the beginning of disease infection. The processor acts as a diagnostic doctor waiting for specific symptoms to arise in exact sequential time intervals or at the same time, which indicates the probability of acquiring a certain disease(information about disease symptoms, timings of symptoms, frequency of occurrence of these symptoms , and intensity of the symptoms are already stored in memory as data, extracted from pathological medical sources) . [33]

(Physiological stress. [34], Health monitoring algorithm [33], Headache [35], body fatigue [35],)

2.12 QFD Quality Function Deployment

The definition of a QFD study :

Is the evolution of a product by translating customer voice, as a first step of 5 different steps which will eventually lead to forming the product ; and the needs for its manufacturing: (Can sometimes be called house of quality , or relationship matrix.).

There can be two major purposed of the QFD study or QFD matrixes. The first purpose is the evaluation and comparison between various commercial products, techniques, or mechanisms (usually 3-5) in terms of how much each product/technique satisfies the customer preferences (requirements). The second purpose is product development, where the customer preferences, which vary in type and importance, are implemented in the product accordingly as product features that serve these preferences. Examples of customer preferences are : Reliability, speed, robustness, price. Examples of product features that serve “Speed” are : Fast detection system, fast product processor , small time interval of the whole measurement.

2.12.1 An Example of A QFD Analysis And Product Development Methodology [36]

<u>QFD Matrixes:</u>

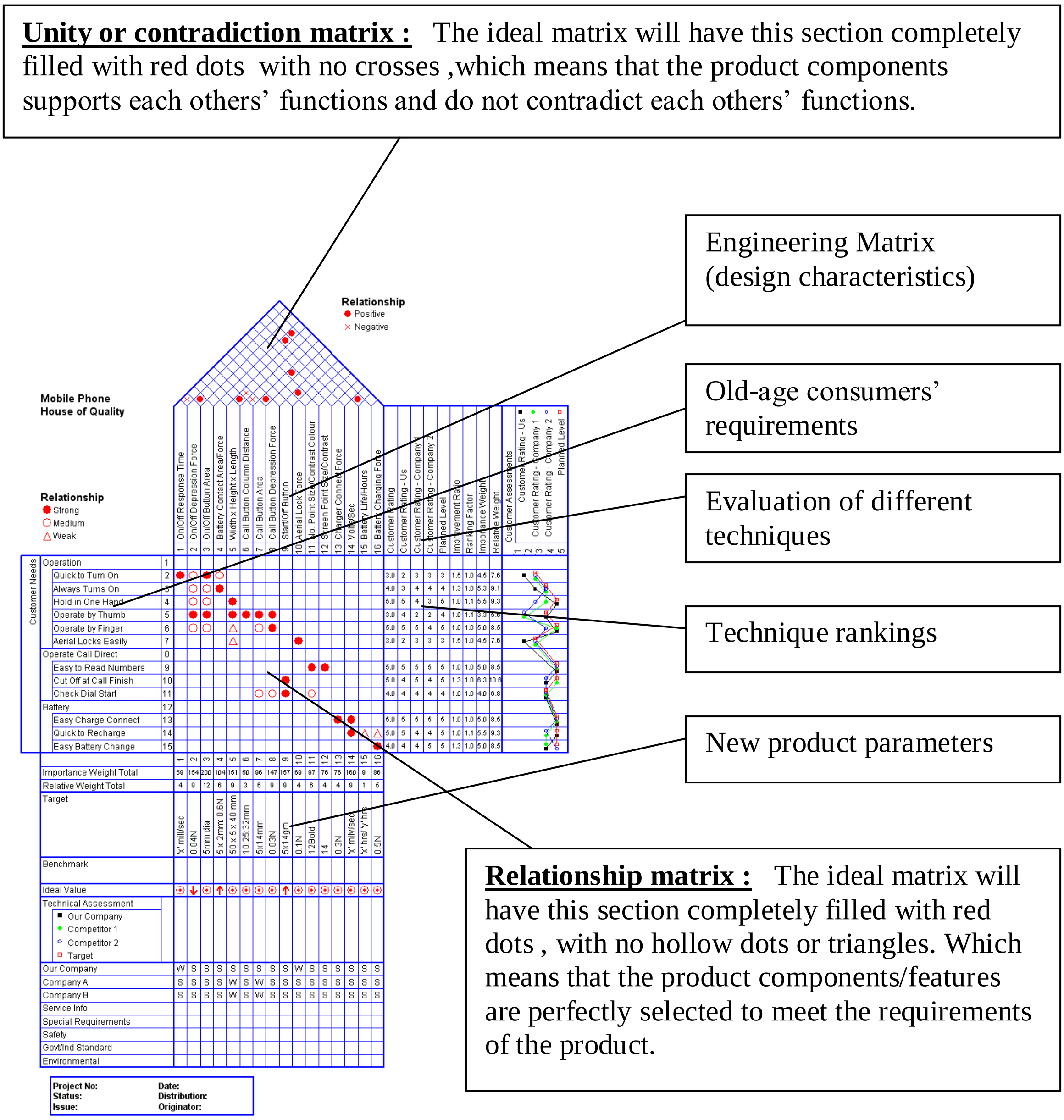


Fig. 2.12.1a Labelled QFD House of Quality matrix.

A Mobile Phone Example:

This is the main QFD matrix (Fig. 2.12.1b) for comparing different models of the product. The customer needs (requirements) are plotted against the design characteristics/features.

The small amount of red dots shows that the product sub-systems do not really serve the product. (That is, serve the requirements of the product, there are barely any relationships between the different parts of the product and the customer needs).

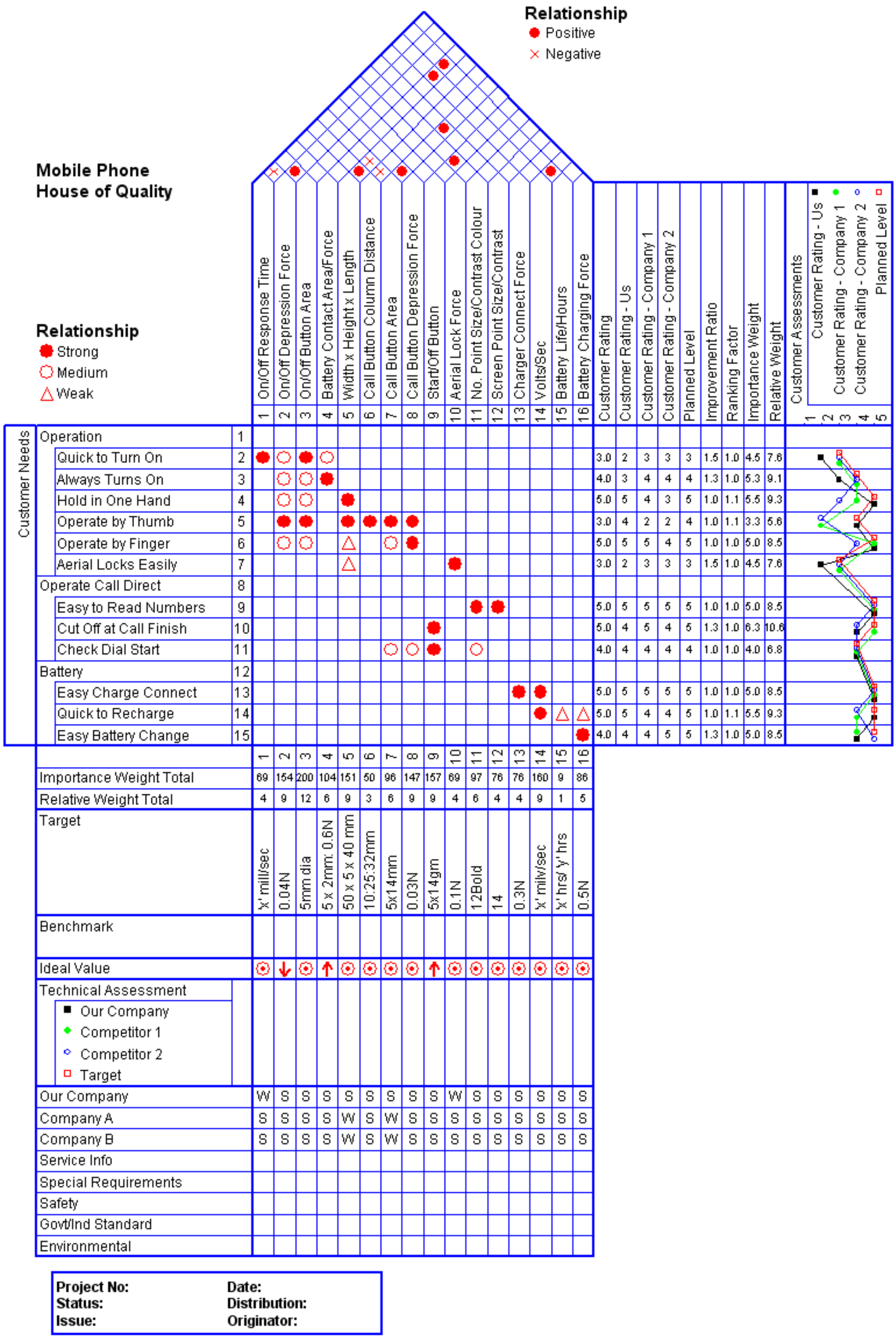


Fig. 2.12.1b QFD matrix (customer needs vs. design characteristics).

A more detailed study can show us the <u>Design Characteristics</u> plotted against the <u>Part Characteristics.</u>

Mobile Phone
Part Characteristics Matrix

Relationship
● Strong
○ Medium
△ Weak

Part Characteristics: 1 Spring Resitivity; 2 Spring W x L x Thick and Profile; 3 On/Off Button Dia; 4 On/Off Button Stem Dia x L; 5 On/Off Button Profile; 6 4 x Cu Springs; 7 4 x Rd Rect Holes in Body; 8 Top Moulding 50 x 12 x 140; 9 Top Moulding Profile; 10 Call Button Mould Dia/Profile; 11 Call Button Spring Resitivity; 12 Call Button Spring Dimens and Profile; 13 Call Button Locations; 14 Aerial Dia & Length in Body; 15 Hotfoil Font & Colour; 16 Red & Green Colour Hotfoil Font; 17 Charger Interference; 18 Battery Contact Spring Res.; 19 Battery Spring Profile

Design Characteristics		Importance Weight	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
On/Off Response Time	1	6.9	●	●	△																
On/Off Depression Force	2	15	●	●	△																
On/Off Button Area	3	20			●	○	△														
Battery Contact Area/Force	4	10						●													
Width x Height x Length	5	15			△				○	●	△										
Call Button Column Distance	6	5.0							●	●	△	●									
Call Button Area	7	9.6										●									
Call Button Depression Force	8	15											●	●	○						
Start/Off Button	9	16									○	●						●			
Aerial Lock Force	10	6.9									○					●					
No. Point Size/Contrast Colour	11	9.7										○					●	○			
Charger Connect Force	12	7.6																	●		
Volts/Sec	13	16																	△	△	
Battery Life/Hours	14	0.9																		△	
Battery Charging Force	15	8.6																		○	●
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Importance Weight Total			201	201	217	60	20	94	91	181	88	302	133	133	44	62	87	170	85	43	77
Relative Weight Total			9	9	10	3	1	4	4	8	4	13	6	6	2	3	4	7	4	2	3
Target			0.5	5mm Cup	Dia Profile	Run Fit 1		5mm Tri	Run Fit 1	To Dwg	All Rads										
Benchmark			0.5	Part No		As 345		Part No	0.2mm												
Ideal Value																					

Project No: **Date:**
Status: **Distribution:**
Issue: **Originator:**

Fig. 2.12.1c QFD matrix (design characteristics vs. part characteristics).

A further more detailed study (Fig. 2.12.1d), shows us the Part Characteristics against the Process characteristics (the manufacturing process of each component). The matrix will now try to study relationships between the sub-parts and the machines that are supposed to build them.

The advantage of this matrix is that it can inform the product engineer how much the machines he will use for the manufacturing of this product are compatible with each and every sub-part. And the most important question.......can these factory machines build the product?

Mobile Phone
Process Characteristics Matrix

Relationship
● Strong
○ Medium
△ Weak

Part Characteristics		Importance Weight	1 On/Off Button	2 Material & Heat Treatment Spec	3 Press Tool Dimensions	4 Moulding Tool Dimensions	5 Moulding Temp & Pressure	6 Battery Contact	7 Press Tool Form	8 Press Tool Gauge	9 Material Hardness	10 Body Moulding	11 Tool Dimensions & Finish	12 Moulding Temp & Pressure	13 Moulding Cooling Temps	14 Call Button	15 Moulding Tool Dimens & Finish	16 Moulding Temp & Pressure	17 Spring Material Hardness	18 Press Tool Dimens & Gauges	19 Hot Foil Temp & Pressure	20 Red & Green Temp & Pressure
Spring Resitivity	1	20		●	○																	
Spring W x L x Thick and Profile	2	20		●	●																	
On/Off Button Dia	3	22				●	●															
On/Off Button Stem Dia x L	4	6.0				●	●															
On/Off Button Profile	5	2.0				●	○															
4 x Cu Springs	6	9.4							●	○	○											
4 x Rd Rect Holes in Body	7	9.1											●	●	○							
Top Moulding 50 x 12 x 140	8	18											●	●	△							
Top Moulding Profile	9	8.8											●	●	○							
Call Button Mould Dia/Profile	10	30															●	●				
Call Button Spring Resitivity	11	13																	●			
Call Button Spring Dimens and Profile	12	13																		●		
Hotfoil Font & Colour	13	8.7																				
Red & Green Colour Hotfoil Font	14	17																				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Importance Weight Total			0	361	241	267	255	0	85	28	28	0	323	323	72	0	272	272	119	119	0	0
Relative Weight Total			0	13	9	10	9	0	3	1	1	0	12	12	3	0	10	10	4	4	0	0
Target																						
Benchmark																						
Ideal Value																						

Project No:	**Date:**
Status:	**Distribution:**
Issue:	**Originator:**

Fig. 2.12.1d QFD matrix (part characteristics vs. process characteristics).

2.13 Literature Review of the Technologies Implemented In The Watch-headphone

Recommendation:

This review supports the customer voice requirement no 5, of the QFD study (ch4), which is the ingenuity of the product.

2.13.1 Commercial Advanced Watches with multiple functions.

Fig.2.13 Commercial Advanced Watches. [37], [38], [39], [40], [41]

Fig. A shows a mobile monitoring system from Loughborough university-UK : This phone can send remote signals for 4 medical health aspects to the doctor holding the phone, including blood pressure and glucose. The device is still under development. Fig. B shows a watch that can measure its owner's speed of movement using Accelerometer technology. Fig. C shows a watch cell phone. Fig. D shows a watch that can measure its owners distance from the ground by means of an Altimeter (measures height). Fig. E shows a Blue tooth MP3 and MP4 watch. Fig. F: (Walkie Talkie) shows a watch that allows communication with friends .Fig. G : Dec/2006- Japan shows a mobile phone that helps patients breath.

2.13.2 Processors size compatibility.

Examples of Small size and high capacity processors that can be used for medical portable devices :

Processors and storage can be really made small and miniaturised, depending on the type of processor we use. Our integrated watch can be as big as this watch (Fig H) , since that most of the storage facilities used in this photo are advanced and miniaturised. This way, our watch can stay close to the size of everyday worn watches. [42]

This Body "vital signs" watch (Fig. 2.13.2) can measure blood oxygenation level, body temperature, BP, heart pulse, and respiratory rate. The last four are the vital signs of the human body which are mentioned in chapter 3.

	
: [43]	: [43]

Fig.2.13.2 Harvard researched medical watch.

2.13.3 MEMS Computer-Chips

The computer chips are becoming smaller and smaller. Semiconductor and wafer technology are now developing what is called “chip-on-MEMS” methodology, where the computer chip which is usually outside the MEMS wafer (in a CMOS circuit) is now part of it. That is, the chip is becoming a tiny built-in part inside the MEMS device. As the technology progresses, future computers will become dramatically miniaturised. [44], [45]

2.13.4 NEMS Computer-chips – Millipede Memory - (Nano-scale Memory Units)

In 2007, IBM has developed the Millipede Memory technology.
It combines the atomic microscope technology and nanotechnology together, to produce 1000 times more storage capacity. The storage units of this device are in terabytes.

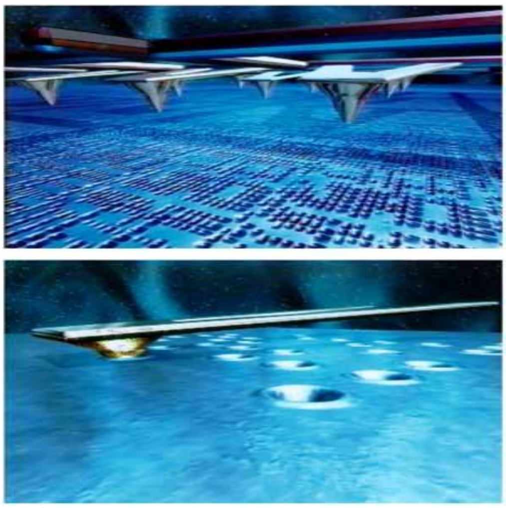


Fig.2.13.4 Millipede Memory. [46]

2.13.5 Processors for Embedded Systems

Embedded processors are small size processors used for a specific purpose: mobiles, pocket computer, minicomputers, PDA s, and other specialised functions like traffic light signal processors. Embedded processors are shrunk in size due to the scarcity of space in the devices they are supposed to fit in. This makes these devices extremely convenient to be added to our limited space watch.

ARM Processors:

Arm processors are processor manufacturers that are specialised in embedded systems for portable devices (similar to our product). Their processor sales have reached up to 75% of the portable electronic devices market.

2.13.6 FMRI Functional Magnetic Resonance Imaging &EEG

<u>Timeline of the development of a commercial EEG product:</u>

Fig.2.13.6 a Emotiv 2006 joysrick. [47]

First, in 2006, this product (Fig.2.13.6a) was developed by “Emotiv” as a brainwave joystick for computer games. This was their first brainwave control headset with 16 electrodes mounted to read the brain signals of the user and interpret them as computer game commands. The computer processor is attached on the rare side of the helmet (red box), as it is shown on the above photo. This processor is part of the helmet; it is not separated like other EEG products. The electrodes used are of a dry type. In other words, it doesn’t need covering the scalp with an electro-conducting gel, as it is the case of a laboratory EEG system.

Only recently, are the EEG products beginning to commercialise, although the EEG and FMRI technology have been developed for a considerable amount of years. The main usage of these products are video games and computer cursor control (a substitute for the computer mouse).

Fig.2.13.6 b Emotiv 2007 joystick. [48]

This is Emotiv's second brainwave control headset (2007) with 14 electrodes (Fig. 2.13.6b). The processor is separated from the helmet (wireless). The product is also used for video games control, but it is fairly smaller in size than the old version. The lower curves shown on the above photo clips to the ears to give the product a firm hold on the head.

This new design makes it easier for the user to wear the product than the old version.

Fig. 2.13.6 c "OCZ Technology" joystick. [49]

Next is the OCZ company joystick, built by "OCZ Technology" (California - Mar/2008) . Similar to the Belgian thermal energy EEG (Fig. 2.13.6d), this product is also made out of 3 dry electrodes for signal identification. The above photo clearly shows the 3 diamond shaped parts of the black bow which goes over the head of the user. The photo also shows the separate processor cube beneath the bow, which is wirelessly connected to the bow.

Fig. 2.13.6 d IMEC Solar EEG product in 4/2008. [50]

The third EEG product was developed by “IMEC” (a Belgian laboratories and research company – in April/2008). This EEG is more advanced than the other types. It is self energized extracting its power from the scalp heat and from light, converting them into voltage. Only 3 electrodes are utilized in this system. This EEG was built to scan brain diseases , plus general brain signal monitoring(for experimental purposes).Gradually, since 2006, the EEG devices are taking the shape of a headphone-like product, which is a concept similar to our proposed product. The processor of this product is separate from the product, and it is actually a processor of a nearby personal computer that wirelessly sends and receives data. The product identifies the users’ brain signal only through the 3 electrodes and a miniaturised integrated circuit.

Fig.2.13.6 e NeuroSky EEG joystick and music headphones. [51] , [52]

Fig. 2.13.6e (above) is the most advanced and latest product (May/2008) of all the above demonstrated EEG systems. Manufactured by NeuroSky California, this product has only one dry electrode. Similar to our convertible product, this product has audio headphones and a built-in miniaturized processor inside the headphones body. Apart from being an EEG product, it can also be used for listening to music.
As a substitute for numerous electrodes, an eye-tracking component was proposed, which is very useful if the product has to be used instead of a computer mouse for surfing and cursor control. This product is mainly built for video games control and cursor control, where the eye-tracking component detects the direction of vision of the eyes to locate the cursor at the exact position where these detected directions point. The eye tracking component is shown on the above photo, a strip, at right angles to the headphone body.

2.14 Summary

A lot of medical techniques where reviewed in this chapter, some are very convenient to be part of a medical product but others are not. From this gathered literature of medical devices, techniques, and products we are going to have our building blocks of the medical product under study. Advanced watch technologies, advanced watches, and an insight of how these technologies work are also briefly explained.

A more detailed explanation is added to explain how certain sensory technologies(ultrasonic)can probe each and every constituent of the blood, or how electric charges can extract sugar molecules from the wrist of the user without even having the slightest sensation on the skin surface.

All of these technologies are purely non-invasive, including the EEG system. There was emphasis on general health status, in the EEG section of this chapter, to support the second most important requirement of the customer voice which is a need of a multi-health measurement device. The nearest product to our more developed product in chapter 7 (multimedia product- look at Appendix A) is the NeuroSky EEG, which contains audio headphones for listening to music. The embedded processor technology, the Millipede technology, and the MEMS computer chips technology are introduced in our study to decrease our convertible product size as much as possible, since that these technologies are part of the miniaturisation science of Nanotechnology.

In the next chapter, chapter 3 we will be evaluating the importance of various measurement techniques and sensor technologies. We will also be evaluating the importance of the product components and features, in order for us to eliminate non-important components and keep important ones as part of the product.

Chapter 3 : Quality Function Deployment (QFD) Evaluations of Product Subsystems

3.1 Introduction

The evaluation of the existing non-invasive medical techniques will be performed using a QFD Evaluation methodology (these will give different weights for different features or customer requirements). After the comparison, a sensor will be nominated. That is, it will have the highest point though a marking system which will be based on the compatibility of the sensor with the customer voice; and it will be given a rank of (1). Then, QFD matrices Quality function deployment will be established to show relationship between components and customer requirements, components with other components, and components with other engineering aspects.

3.2 The Selected Segment and Statistics

The elderly segment of the UK society are not happy with the portable devices that reads there medical status (if they do exist in the first place). Different people of variable income, demography, and education level have common opinions that the portable medical technology is not good enough. Since they have a lot of health problems, due to the old age, they have claimed that they are in an urgent need of a portable medical device that can inform them about their exact health status. Frankly speaking, a large percentage of them is complaining that this device doesn't even exist, and that they hate the fact that electronic medical devices can only test their health status inside the hospital and that these devices are not portable, which makes it most of the time useless, especially when an old woman /man have serious health problems which makes it hard for them to go to the hospital (transport). Most old men/women have complained about the fact that portable general health measurement devices are not even sold in the market (pharmacies and hospitals) and that most of them are specialised for one type of measurement(glucose measurement device, cholesterol measurement device, body temperature thermometer).

A lot of interviewed samples of old age people have commented about the existence of portable electronic devices that are watch-like devices but are much larger in size than the normal watch , these devices , as they have claimed , reads blood pressure automatically with a press of a button. Around 70% of the questioned old men/women have recommended these devices, but they have complained from the fact that they can't be worn 24 hours, since that they are large in size.

3.3 The Qualitative and Quantitative Research Methodology

This research methodology establishes the customer requirements from the opinions of people in a conversation –wise manner (qualitative research) writing there subjective personal opinions on paper. At the same time it will accurately measure quantitative selections of particular features with questionnaires.

As a first step, we will interview some of the elderly people (40-70 years) in London. The interviews will produce a statistical report of how much the present non-invasive medical portable products are needed or demanded by them , and what is really missing or the disadvantages of such devices. According to the QFD system, the registered information extracted from the individuals is called “Customer Voice”.

The voice or opinion of the interviewed people will then be transformed into product requirements in the form of comprehensive and short statements; These statements should show exactly what they need, or expect from their portable medical devices.

3.3.1 Qualitative (about opinions and preferences)

A group of 20 participants in the streets of London (age: approx.40 -70) where interviewed (fast interviews in the street) and asked about the features that they would like to be present in their own portable health watch, if they should have one.

Step1 : Asking them questions to extract ideas about what their best device should have or include.

E.g.

"What health aspect do you prefer to be measured before any other aspect?"

This question was asked to find out if certain types of measurements are more important than other type of measurements for the old-age segment.

Answers of the segment imply that: There is no preference. Because they have different types of diseases, each individual had selected a measurement of his disease or his own health problem.

"How do you think the device should look like?"

This question allows us to have a basic idea of how the device should look like.

Answers of the segment imply that: Appearance is not an issue for the segment, although some people have mentioned the idea of "a good looking device".

"Do you prefer the device to be a portable device kept in your pocket, or should you prefer it to be built-in inside your watch?"

To confirm that watches and mobile phones have a much stronger business-image than portable medical devices.

Answers of the segment implies that : They prefer it to be a portable medical watch that shows time on the screen as well as medical measurements of their health status.

"What if the device is expensive, are you going to buy it?"
To make sure that the device will not be that expensive that the old-age segment will not be able to purchase it.
<u>Answers of the segment imply that</u>: Most of the interviewed samples have claimed they prefer a cheap product, but they can still purchase expensive ones if it really good and if it can measure a lot of health aspects.

"Do you really need a medical portable device?"
This question is established to emphasise and confirm the essential need for a general health measurement portable device.
<u>Answers of the segment imply that</u> : There is a great need from the elderly segment for such devices , and most of the questioned individuals have claimed that they don't think that these devices exist since that they have never came across them in supermarkets, pharmacies, or electronics shops in the UK.

<u>Step2</u> **:** Writing their opinions on a notebook.

E.g.

<u>Here Are some of the Opinions Recorded by the Interviewer :</u>

"It takes a lot of time to measure my blood sugar level"

"I can't use these devices, ………..my daughter knows how to use them and she helps me in taking the reading."

"I have a good wrist – blood pressure measuring device, but it's too big and heavy."

"It hurts when my finger is pinched .....sometimes a lot of blood comes out …….and it is hard for me to stop it , I need something safer and more practical in order to measure my glucose or blood sugar level".

<u>Step3</u> : The conversion of customer voice (the above mentioned opinions) into requirements (summarised customer preferences) :

Table. 3.3.1 Conversion of customer voice into customer needs/requirements.

Customer voice → **(conversion)**	**Requirements**
-It hurts when my finger is pinched.	safety
-I want a product that has a fare price.	moderate price
- Sometimes the readings are totally different,…………… I think the device I am using is not that accurate. (invasive glucose device)	accuracy of readings
-I have a good wrist – blood pressure measuring device, but it's too big and heavy.	comfort
- I never buy these devices,……. I have other more dangerous diseases to worry about than blood-pressure. I need a device that can lower my blood pressure if possible, like the pills I swallow to level up my blood-pressure.	Design ingenuity
-It takes a lot of time to measure my blood sugar level.	quick measuring
- I would like to buy something that can read a lot of things , not only my heart pulse rate(e.g. sugar level,	Design multi-health-measuring

cholesterol level, No of calories, nutrition level, my temperature if I am not feeling well).	
-sometimes I forget to use it everyday.	Automation and reliability
- I can't see clearly …..the numbers on my device screen ………,although the screen is large. -I can't use these devices, ………..my daughter knows how to use them and she helps me in taking the reading.	Solutions for the "old age" problems.
- The colours are not that good, I want something that looks awesome.	attraction
- I would love to have something that is easy to use, because I am finding difficulties using my arm-blood pressure device.	easy to use

3.3.2 Quantitative (close-ended multiple choice questionnaire)

Step4 : A group of 100 participants in the streets of London (age: approx.40 - 70) were given close-ended multiple choice questionnaire to fill instantaneously. There is only one question to be answered(Table. 3.3.2a). The segments given the question included: Different occupations , men and women , different nationalities living in the UK, living in different regions outside and inside of London, suffering from serious and non-serious diseases, normal and physically disabled, normal and obese). The participants were initially asked about their age to make sure that they fall in the required age-range.

The questionnaire is made up of a 1 page and 1 question, and it took the participants a maximum time of 1 minute to answer the question. This question is established from the **customer requirements** extracted from customer opinions.

The question states:

Table. 3.3.2a Close-ended multiple choice questionnaires.

Which of the following features you need most if you are to have a portable medical device?
(tick your choice)

Safety	
moderate price	
accuracy of readings	
comfort	
Design ingenuity	
quick measuring	
multi-health-measuring device	
reliability	
Solutions for the "old age" problems.	
attraction	
easy to use	

Table. 3.3.2b Requirements frequency of occurrence.

(The number of times each requirement is being selected from a questionnaire)

Requirements	**Frequency of occurrence.**
1-Solutions for the "old age" problems.	15
2- Multi-health-measuring design/system	14
3- Accuracy of readings	14
4- Easy to use	12
5- Design ingenuity	8
6- safety	8
7- comfort	6
8- reliability	5
9- moderate price	4
10-attraction	3
11-quik measuring	3

Frequency of occurrence converted to a rate of (0-5):

Now we will change these values (occurrence values) to a simple value between 1 and 5 (1-5), so that all the "sensor techniques" will be ranked according to it, and they will be given a ranking system (1-5). These sensor rankings has to have a ranking less than or equal to the converted ranking which is exactly 5.

The above table is the ideal rank, generating the qualities and features of the ideal portable health measuring product.

That is, this above table is the new product itself , but in an "information form".

Different requirements of this form (universality, reliability, safety ,…..etc) resemble different design aspects of the new product with different proportions, important and unimportant, waiting to be considered before building or manufacturing the product.

Table. 3.3.2c Frequency of occurrence converted to a max. rank of 5.

Requirements	**FOC frequency of occurrence** (15 patients)	Planned level on the QFD graph=customer voice ideal values = **FOC/3**
1-solutions for the "old age" problems	15	5
2- Multi-health-measuring system	14	4.7
3- accuracy of readings	14	4.7
4- easy to use	12	4
5- design ingenuity	8	2.7
6- safety	8	2.7
7- comfort	6	2
8-reliability	5	1.7
9- moderate price	4	1.3
10-attraction	3	1
11-quick measuring	3	1

3.4 Explanation of the Rating System of The Evaluation Tables

A = No. of features supporting the requirement. (max 5 points)

B = Importance/weight of feature. (max 5 points for each feature).

C =Requirement value. (max 5 points)

C can be : = D equivalent to the preferences of customer voice.

< D does not meet the demands of customer voice.

> D exceeds the demands of customer voice.

D = Customer voice requirements value. (max 5 points)

Example:

A No of features(max 5 point)	**B** Importance Weight	**C** = The Sum (Sigma) of the importance of the features(B).
1	5= Very important	5
1	3 = important	3
1	1= slightly important	1
1	0= not important	0
1	-1=opposite to requirement (needs 1 to become 0=not important).	-1 +
		= 8

Total Requirement value for 1 feature (A=1) = (1 x B) =C

Total Requirement value when (A=2) = (B1) + (B2) = C

Total Requirement value when (A=3) = (B1) + (B2) + (B3) = C

(B1=importance of the first feature , B2=importance of the second feature , B3=importance of the third feature , B4=importance of the fourth feature ,

3.5 QFD Evaluations of the (4) Best Selected Sensors

I) MEMS Airborne (Non- contact) AE/ULT.SO Medical sensor.

II) A CMOS –based (mille-range) skin-contact and piezoelectric sensor.

III) MEMS Infrared Medical sensors (non-contact).

IV) MEMS Electromagnetic method (noncontact).

3.5.1 Reasons Why These 4 Specific Techniques were selected

Compatibility with The Medical Watch under Study: These sensors are all entirely non contact (except for II-CMOS skin-contact), which will enable medical measurements of the hand-wrist area while the watch is experiencing loose and random movements away and toward the wrist skin. This type of system with unfixed sensor positions is in a great need for a non-contact system. The CMOS sensor is selected for its high resolution. The CMOS BP system is unique in this feature. The other above systems lack the high resolution of the CMOS sensor. Attaching the CMOS sensor to the watch means that the watch belt should always be in contact with the system and this will hinder the practicality of the product. Therefore, it was suggested that an extra ribbon containing the sensor should be worn by the user, should the CMOS sensor evaluation table prove that it is the NO. 1 (best) sensor to be selected as the medical sensory method of the watch. The ribbon will be made out of a thin rubber layer so that it will be comfortable for the user wearing it. Two sensors will be attached to the ribbon so that they will always be sticking to the 2 main wrist veins area to the left and right of the wrist. The measurement information will be wirelessly transmitted to the watch, as this technique is previously applied in the medical watch literature.

Table. 3.5.2 (I) : Evaluation Table For MEMS AE/ULT.SO (non-contact) Medical Sensors

Requirements	**Requirement Features (adv. /disadv.)**	**A**	**B**	**C**	**D**
1-Solutions for the "old age" problems	The non-contact AE/ULT.SO techniques are very suitable and safe for old people, unlike the inflation products that might squeeze up their arm tissue. **AE/ULT.SO are not proven to work if miniaturised.**	1	4 =4	4	5
2- **A multi-health-measuring system**	1) ULT.SO can provide a 3D image of many body organs. 2) AE/ULT.SO can be used for the detection of all sorts of particles in the blood stream, which prepares the system for further developments increasing the number of detected particles for health monitoring services.	2	3 + 2 ——— =5	5	4.7
3- Accuracy of readings	1) The fact that the sensor is non-contact eliminates one common uncertainty factor between all sensors, which is the precise position of the sensor exactly on the wrist vein. 2) Some non-contact ULT.SO sensors are capable of sensing a collection of veins or capillary beds which makes the measurement much more accurate.	3	1 1 +1 ——— =3	3	4.7

	3)The nature of the technique is more accurate than other techniques(waves).				
4- Easy to use	The non-contact ULT.SO measurement makes it easy. **AE/ULT.SO are not proven to work if miniaturised.**	1	2 =2	2	<u>4</u>
5- Design ingenuity	1) Some AE/ULT.SO sensors can withstand high temperatures. (durable). 2) An advanced wave propagation system.	2	1 +2 ——— =3	<u>3</u>	<u>2.7</u>
6- Safety	AE/ULT.SO has no danger on the skin or any part of the human body.	1	4 =4	4	<u>2.7</u>
7- Comfort	The non-contact AE/ULT.SO detection method will allow the watch body to move freely against the wrist.(unlike the available BP devices)	1	4 =4	4	<u>2</u>
8- Reliability	Farely reliable **AE/ULT.SO are not proven to work if miniaturised.**	1	2 =2	<u>2</u>	<u>1.7</u>
9- moderate price	1) AE/ULT.SO can sometimes be expensive.	1	=1	1	<u>1.3</u>
10- Attraction	The attraction of the watch will rise from its numerous functionalities of ULT.SO added to it, a perceptive sort of attraction.	1	2 =2	2	<u>1</u>
11- Quick measuring	AE/ULT.SO will provide continuous monitoring of BP, 1 reading will occur automatically every 5 sec through the hours of the day.	1	4 =4	4	<u>1</u>

Table. 3.5.3 (II): Evaluation Table for CMOS –based (mille-range) Skin-contact And Piezoelectric Sensor

Requirements	**Requirement Features**	**A**	**B**	**C**	**D**
1-Solutions for the "old age" problems	The sticking factor will create a problem for the elderly people.	1	2 =2	2	5
2- **A multi-health-measuring system**	Contact piezoelectric accelerometers can be used as a heart pulse sensor when positioned nearby the wrist-vein pulsing area.	1	5 =5	5	4.7
3- accuracy of readings	Considerably accurate.	1	5	5	4.7
4- easy to use	The user has to make sure that the watch body is always attached to the skin, which makes measurement of blood pressure or other medical aspects a difficult task.	1	1 =1	1	4
5- Design ingenuity	1) Ingenuity in detecting the expansion of the vein or the vibration of pressurised veins. 2) Bad ingenuity of the sensor, since that it should always be attached to the skin.	1 1	5 - 3 ____ =2	2	2.7
6- safety	Safe (the sensor does not emit any sort of rays or radiations.	1	3 =3	3	2.7
7- comfort	Uncomfortable: the watch belt has to be sticking to the surface of the skin for measurement to occur.	1	1 =1	1	2

8-reliability	Relatively reliable.	1	2 =2	2	1.7
9- moderate price	Very Cheap price.	1	1 =2	1	1.3
10-attraction	Not applicable (1 will be given instead of zero because the QFD marks are between 1 and 5).	1	1 =1	1	1
11-quick measuring	Relatively moderate speed.	1	1 =1	1	1

Table. 3.5.4 (III) : Evaluation Table For Infrared(noncontact) Medical Sensors

Requirements	**Requirement Features**	**A**	**B**	**C**	**D**
1-Solutions for the "old age" problems	Compatible with biological measurement.	1	2 =2	2	5
2- **A multi-health-measuring system**	1) Infrared identification technology is very specialized in particle identification of the body. 2) Infrared technology is a natural biological particle identifier. 3) IR sensing might have a diffraction method which is used by some of the EEG signal detection technologies in Japan.	1 1 1	1 1 +3 =5	5	4.7
3- Accuracy of readings	Very accurate.	1	5 =5	5	4.7

4- Easy to use	1) Easy to use. 2) Clean and extremely non-invasive.	1 1	1 + 3 ——— =4	4	4
5- Design ingenuity	High design ingenuity.	1	3 =3	3	2.7
6- Safety	Relatively safe.	1	3 =1	3	2.7
7- Comfort	Comfortable because it is a noncontact system.	1	4 =4	4	2
8- Reliability	Reliable	1	2 =2	2	1.7
9- Moderate price	The chosen function of the infrared system in the watch is the detection of the **oxygenation levels** of the blood. This task needs a couple of ray receiving diodes that will be situated in different places along the belt which will be a little bit costly.	1	1 =1	1	1.3
10-Attraction	Infrared devices will sometimes emit red light which can attractive.	1	1 =1	1	1
11-Quick measuring	Fairly quick	1	3 =3	3	1

Table. 3.5.5 (IV): MEMS Electromagnetic Method (noncontact)

<u>Requirements</u>	**<u>Requirement Features</u>**	**A**	**B**	**C**	**D**
1-Solutions for the "old age" problems	The electromagnetic method is a very safe method since that it receives waves and does not emit waves.	1	2 =2	2	5
2- A multi-health-measuring system	This method can quantify the amount of haemoglobin in the blood flowing in the wrist vessels since that haemoglobin has a lot of iron that triggers the EMF of the watch. **<u>Unfortunately this method is never applied which makes it an extremely weak evidence that electromagnetism can really measure blood speed.</u>** In addition, electromagnetism is not widely used for medical applications.	1	1 =1	1	4.7
3- Accuracy of readings	The system monitors the speed of blood in veins, which doesn't entirely indicate blood pressure but is a basic factor.	1	3 =3	3	4.7
4- Easy to use	Since that it s a noncontact technique it will be easily used.	1	4 =4	4	<u>4</u>
5- Design ingenuity	Electromagnetism can detect some of the positively and negatively charged particles inside the wrist vessels (glucose watch uses an electromagnetic detector to measure glucose particles penetrating out of the wrist into the watch: literature chapter 2). <u>There is no proof that electromagnetism can measure BP.</u>	1	2 =2	2	2.7

6- Safety	Safe (no rays are emitted from the system): The movement of the iron particles in our wrist veins will trigger this system, generating current. Still, there is no proof that electromagnetism can measure blood speed or BP.	1	2 =2	2	2.7
7- Comfort	Very comfortable : This system is high in simplicity, no need for cuff inflations or other complications.	1	3 =3	3	2
8- Reliability	Twenty-four (24) hour blood pressure monitoring, as long as the blood stream contains iron.	1	3 =3	3	1.7
9- Moderate price	Cheap.	1	3 =3	3	1.3
10-Attraction	Not applicable	1	1 =1	1	1
11-Quick measuring	Constant monitoring of blood pressure.	1	4 =4	4	1

3.5.6 The Rating Table

The rating table shows which sensor is more compatible with the customer voice that was established previously.

In this table we are choosing the nearest values to the D values, for example, (3,2,0,1) 5 , the nearest value to 5 out of 3 and 2 and 0 and 1 is 3.

Table. 3.5.6 Rating of the 4 non-invasive measurement techniques.

Requirements	**i)AE/ULT.SO**	**ii) skin contact**	**ii) Infrared**	**iv)Ele.magn**	**(D)**
1-Solutions for the “old age” problems.	4	2	2	2	**5**
2- **Multi-health-measuring design**	5	5	5	1	**4.7**
3- accuracy of readings	3	5	5	3	**4.7**
4- easy to use	2	1	4	4	**4**
5- Design ingenuity	3	2	3	2	**2.7**
6- Safety	4	3	3	2	**2.7**
7- Comfort	4	1	4	3	**2**
8-relaiability	2	2	2	3	**1.7**
9- Moderate price	1	1	1	3	**1.3**
10-Attraction	2	1	1	1	**1**
11-Quick measuring	4	1	3	4	**1**
How many points are close to the D value.	**5points**	**7 points**	**8 points**	**3 points**	

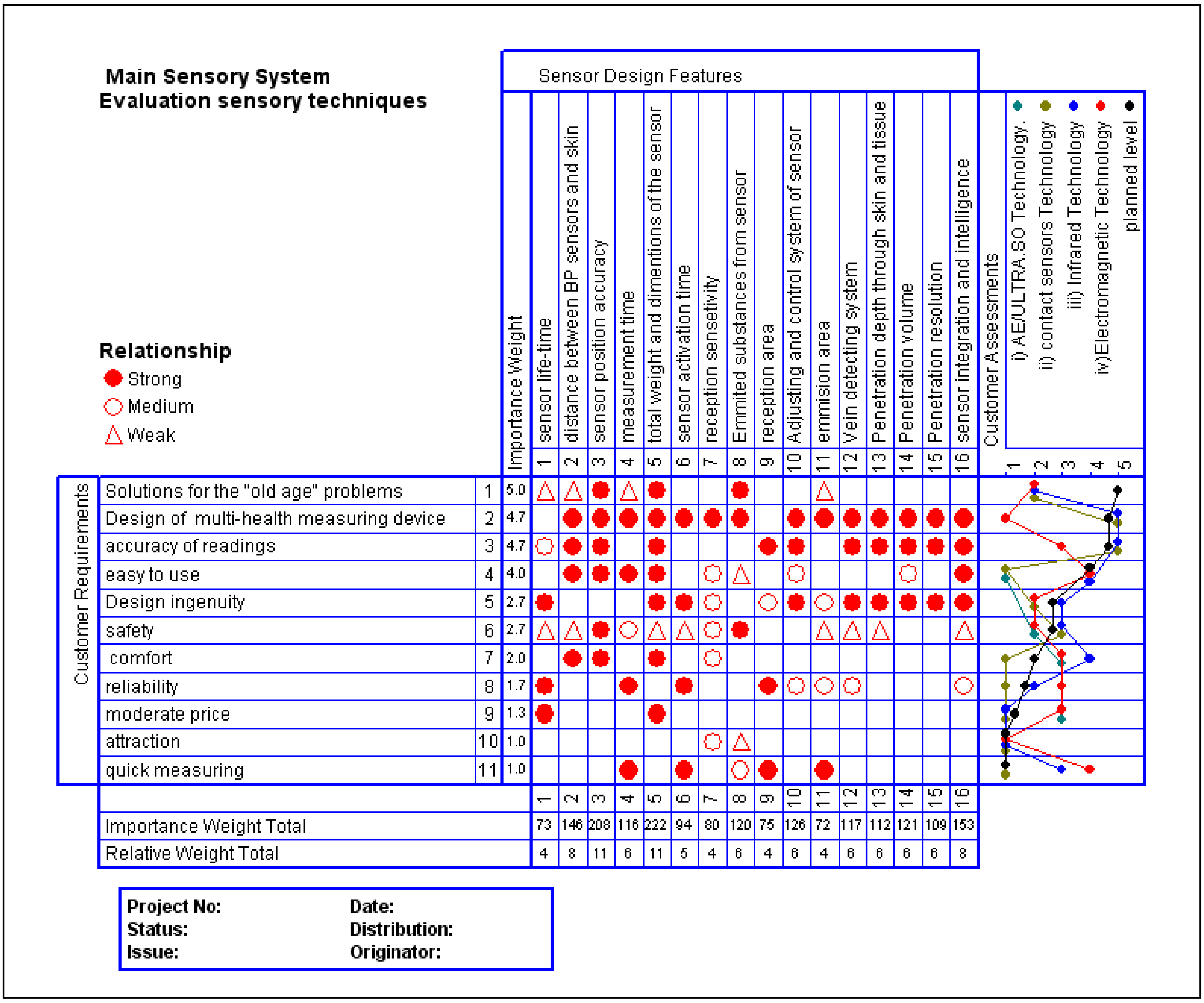
The Best 2 Techniques Are :

The closest available sensor to the patients needs is technique III) MEMS Infrared sensors (non-contact) .

The second closest available sensor to the patients needs is technique II) "CMOS MEMS" skin-contact piezoelectric sensor.

3.6 Sensory Systems Evaluation Matrix: Customer Needs Against Design Features Matrix

This matrix doesn't evaluate the whole product; the evaluation is only for the non-invasive sensory capabilities and its compatibility, adding it to a portable watch device.



Matrix. 3.6 Sensory Systems.

3.6.1 Plotting the Medical Techniques Values

The values of the 4 techniques are plotted in the customer assessment part of the above QFD matrix (on the right side of the matrix). This will determine (visually) which technique is nearest to the requirement value. The requirement values are equal to the importance weight shown on the matrix, these values are plotted forming a red line on the graph (another name is planned level).

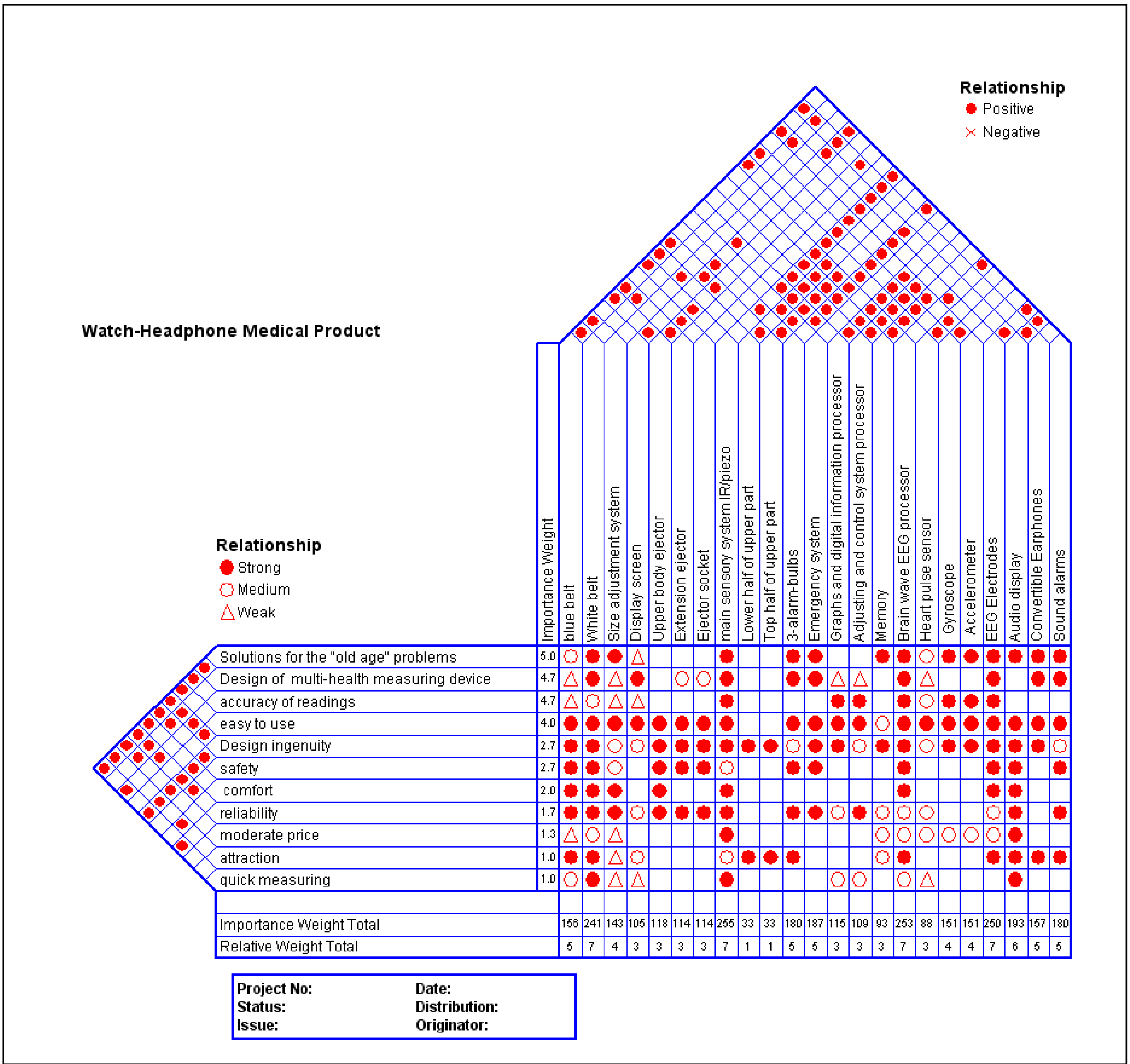
3.6.2 The 3 Most Important Design Features

1) Total weight and dimensions of the sensor. (Normal size/MEMS) (222 importance weight).
2) Sensor position accuracy (208 importance weight).
3) Sensor integration (153 importance weight).

The most important design feature (scoring 222 points) that extremely satisfies customer requirements is about the size and dimensions of the sensor, justifying our introduction of MEMS technology in this study to make the product as practical and portable as possible.

These 3 features will be further studied through more QFD analysis matrixes. First they will be transferred as part of the headphone-watch design feature matrix.

3.7 Component Weighting Matrix: A Product Development Matrix



Matrix. 3.7 Component Weighting.

In this matrix, the customer needs are plotted against product component types. Through this matrix unnecessary and trifle components are differentiated from basic and primary components. In addition, the unity between components is shown by a pyramid-grid above the components matrix. If there is any contradictions in the functions of any 2 components an x mark (cross) should be registered. Fortunately, in the above matrix there are no crosses.

3.7.1 Filtering The Most Important Components Out of The matrix

Now, the most important components will be selected. The most important components are revealed by a maximum number of red dots registered for each component. Out of these components, a design feature matrix will be produced.

Table. 3.7.1 The 8 most important components (in order of importance).

	Order of importance	**Importance magnitude**
IR/piezo sensor	Most important	255
EEG system(processor and electrodes)	Second important	253
White belt	Third	241
Emergency system	Fourth	187
Three-alarm-bulbs	Fifth	180
Sound alarm	Sixth	180
Convertible earphones	Seventh	157
Blue belt	Eighth	156

3.8 Integrated Matrix: A Product Development Matrix

This matrix combines the most important components/feature of the sensory matrix with the most important components of the “watch-headphone product” matrix, at the same time.

The Customer needs are on the left side and the Design features are on the right side.

Watch-Headphones Medical Product

Relationship
- ● Strong
- ○ Medium
- △ Weak

Feature Design

Cutomer Requirements	#	Importance Weight	1 Sensor position accuracy	2 Sensor integration and intelligence	3 total weight and dimensions of sensor	4 White belt detection permeability of contained sensors	5 White belt elasticity value	6 White belt Rigidity value	7 Audio display vocal clarity value	8 Audio display verbal demonstration clarity value	9 Audio display high volume limit	10 Brain wave EEG processor capacity	11 EEG Electrodes reception area	12 blue belt elasticity value	13 blue belt detection permeability of contained sensors	14 Sound alarms high volume limit	15 Emergency system rescue time	16 Emergency button accessibility in critical time
Solutions for old age	1	5.0	●		●		○	○	●	●	●	○	○	○		●	●	●
Multi-health-measuring system	2	4.7	●	●	●	●			○	○	○	●	●		●	●		
accuracy of readings	3	4.7	●	●	●	●						○			●			
easy to use	4	4.0	●	●	●		●	△	●	●	●	○		●		●	●	●
Design ingenuity	5	2.7		●	●	●	●	●	●	●	●		●	●	●	●	●	●
safety	6	2.7	●	△	△		△		○	○	○		●	△		●	●	●
comfort	7	2.0	●		●		○		○	○	○		○	○		○		●
reliability	8	1.7		○		△	●	●	●	●	●	●		●	△	●	●	●
moderate price	9	1.3			●							△	●			●	●	●
attraction	10	1.0											●			●		
quick measuring	11	1.0				○	●							●	○	○		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Importance Weight Total			208	153	222	114	108	59	149	149	149	100	133	108	114	217	157	175
Relative Weight Total			9	7	10	5	5	3	6	6	6	4	6	5	5	9	7	8

Project No: **Date:**
Status: **Distribution:**
Issue: **Originator:**

Matrix. 3.8 Integration of the most important components/features.

Still, this matrix showed that there are components of extreme importance. Therefore these components will be further produces into more sub-components, and the other unimportant ones will be ignored, in the next matrix to come.

3.8.1 From "Relative Importance Weight" to "Importance Weight"

Now, a part characteristics matrix will be built. In the part characteristics matrix the feature design section which is on the right hand side in the above matrix will be on the left hand side in the part characteristics matrix. First we will convert the Relative Importance Weight values (RIW), a horizontal grid at the bottom of the above matrix (Fig 3.8) to values between 0 and 5, and placing it vertically in the coming matrix to become " Importance weigh" (instead of relative importance weight). The highest weight in the above matrix has a score of 222; this will be equivalent to 5:

Table. 3.8.1 The conversion of RIW values (1-10) to proportional values of (1-5).

Design features	**Relative Importance Weight RIW**	**RIW/2**
Sensor position accuracy	9	4.5
Sensor integration	7	3.5
total weight and dimensions of sensor	10	5
White belt detection permeability of contained sensors	5	2.5
White belt elasticity value	5	2.5
White belt Rigidity value	3	1.5
Audio display vocal clarity value	6	3
Audio display verbal demonstration clarity value	6	3
Audio display high volume limit	6	3

Brain wave EEG processor capacity	4	2
EEG Electrodes reception area	6	3
blue belt elasticity value	5	2.5
blue belt detection permeability of contained sensors	5	2.5
Sound alarms high volume limit	9	4.5
Emergency system rescue time	7	3.5
Emergency button accessibility in critical time	8	4

3.9 Part Characteristics Matrix : A Product Development Matrix

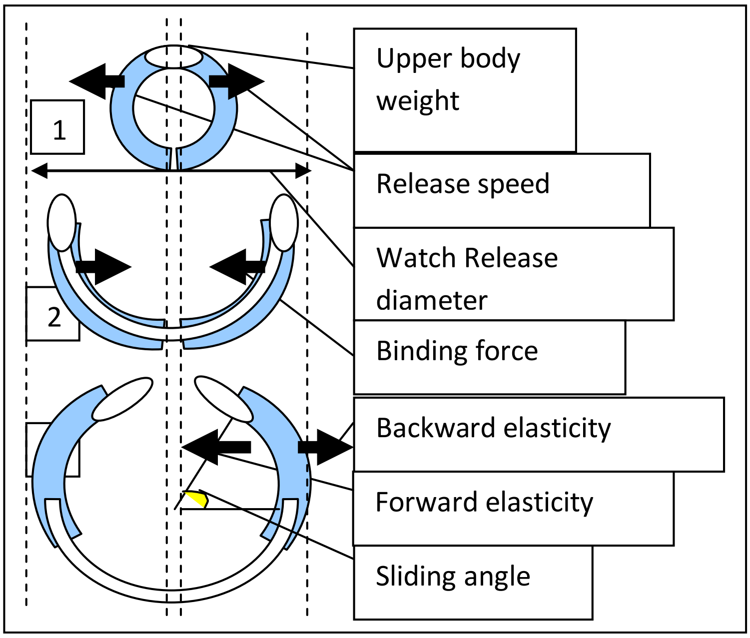


Fig. 3.9a Parameters of the conversion process.

This matrix emphasises the most important characteristics of the watch-headphone conversion process. The most important features and components of the conversion process will automatically be revealed. The QFD software used will automatically calculate importance of features and components by calculating how many dots a certain characteristic has on the matrix, how important are the customer needs connected to these dots characteristics, and what type of dots are registered. The importance of features and components are calculated using a specific mathematical product made out of 2 variables. The rule is as follows:

● = 9 points; ○ = 3 points; △ = 1 point

Example:

Importance weight Column A	Belt dimensions Column B
3.2	●
2	○
1.5	△

Fig. 3.9b The feature column multiplied by (x) the Importance weight column.

"Importance Weight Total" (situated down the matrix) of a specific feature or component	=	Each shape value(circle , triangle) of this specific feature . (Column B of Fig 3.9b)	X	The Importance weight value relevant to this shape. (Column A of Fig 3.9b)

The product of the 2 columns shown in Fig 3.9b (importance weight total) =
Red circle x (3.2) + white circle x (2) + triangle x (1.5)

=> "importance weight total" of Fig 3.9b = (9) x (3.2) + (3) x (2) + (1) x (1.5)

=> "importance weight total" of Fig 3.9b = 28.8 + 6 + 1.5

=> "importance weight total" of Fig 3.9b = 36.3

That is, the feature (belt dimension) has an importance weight value of 36.3.

The Quotient of RIW value and 2 will be inserted as importance weight of the design features in a more detailed matrix of the “watch headphone conversion process”, showing the Design features plotted against the Part Characteristics.

watch-headphones conversion process

Relationship
- ● Strong
- ○ Medium
- △ Weak

		Importance Weight	1 Upper body weight	2 blue belt binding force	3 white belt binding force	4 Watch Release diameter	5 watch release speed	6 blue belt forward elasticity	7 white belt forward elasticity	8 Sliding angle	9 blue belt backward elasticity	10 white belt backward elasticity
Sensor position accuracy	1	4.5										
Sensor integration and intelligence	2	3.5										
total weight and dimensions of sensor	3	5.0										
White belt detection permeability of contained sensors	4	2.5		△	△			△	△		△	△
White belt elasticity value	5	2.5		●	●	●	●	●	●	●	●	●
White belt Rigidity value	6	1.5		●	●	●	●	●	●	●	●	●
Audio display vocal clarity value	7	3.0										
Audio display verbal demonstration clarity value	8	3.0										
Audio display high volume limit	9	3.0										
Brain wave EEG processor capacity	10	2.0										
EEG Electrodes reception area	11	3.0										
blue belt elasticity value	12	2.5		●	●	●	●	●	●	●	●	●
blue belt detection permeability of contained sensors	13	2.5		△	△			△	△		△	△
Sound alarms high volume limit	14	4.5										
Emergency system rescue time	15	3.5										
Emergency button accessibility in critical time	16	4.0										
			1	2	3	4	5	6	7	8	9	10
Importance Weight Total			0	64	64	59	59	64	64	59	64	64
Relative Weight Total			0	11	11	11	11	11	11	11	11	11

Project No:	**Date:**
Status:	**Distribution:**
Issue:	**Originator:**

Matrix. 3.9c Most important component features against the Part Characteristics.

This Product development matrix shows the most important component features against the Part Characteristics. The benefit of this matrix is that certain product aspects will be highlighted. For example, watch release diameter is an important parameter which if it is to be faulty can affect the strength of the force which keeps the headphones firmly sticking to the users head.

Reproducing the “white belt”:

In Table.3.7.1, we have determined the 8 most important components. The first component which is the main sensory system is excessively reproduced in chapter 5. The second most important component which is the EEG system will not be reproduced because of feasibility issues. The third component which is the white belt can be reproduced, and it is quite feasible to do so. Some mechanisms will be added to this component since that it is the third most important piece in the product. We will be using a “Mechanism Feature Matrix.” This matrix will produce an added improvement to the main function of the white belt.

After determining the basic mechanisms of the white belt, features for these mechanisms have to be determined too. The mechanisms (should have movements) are registered under the “Function features column” and the description of those features are listed under “the mechanism features”.

Mechanism Feature Matrix

Relationship
● Strong
○ Medium
△ Weak

Function Features	#	Importance Weight	1 speed of automatic contraction	2 speed of automatic extension	3 nature of contraction button	4 nature of extension button (automatic/non)	5 feasibility of mechanism	6 type of mechanism	7 end of contraction control	8 adjustments of extension		
The sliding of the white belt out of the blue belt to form the headphones.	1											
automatic contraction of the watch	2	1.0	●	○	●		●	●	●			
automatic extension of the white belt	3	1.0	○	●		●	●	●		●		
	4	0.0										
			1	2	3	4	5	6	7	8		
Importance Weight Total			12	12	9	9	18	18	9	9		
Relative Weight Total			13	13	9	9	19	19	9	9		

Project No:	**Date:**
Status:	**Distribution:**
Issue:	**Originator:**

Matrix.3.9d Mechanism Feature Matrix of the white belt component.

3.10 Summary

The most important chapter of the project is chapter 3, where the sensory techniques and components of the convertible watch are evaluated, so that the less important and extremely important features are clearly distinguished. In this evaluation chapter, the best sensory technique is revealed using a numerical weight system. And the critical product components are filtered by means of a QFD dot relationship system. The trifle components are ignored. The utilisation of the QFD matrixes has been accomplished by a constant filtering and amplification of the components. In other words, selecting the most important techniques and components out of a matrix, so that they can be further expanded, and once again inserted in a matrix selecting the most important components or design features. Repeating the process again and again. This design methodology has been applied to make sure that the final features and components under study completely fills the demand gaps formed by the design requirements. The QFD evaluation and product design system is a very flexible system. This system can determine how much relevant each and every component of a product to the customer voice and to each other.

In the next chapter we will be carrying out blood pressure BP readings experiments to be implemented in the product's automation system, as readings correction and compensation values.

Chapter 4 : Blood Pressure (BP) Experiments

4.1 The Reason for Doing These Experiments

(http://www.firstaidwarehouse.co.uk/products/medical-equipment/blood-pressure-monitors/omron-r7-wrist-blood-pressure-)

Fig. 4.1 (a) Oscillatory BP devices privately used for blood pressure measurement.

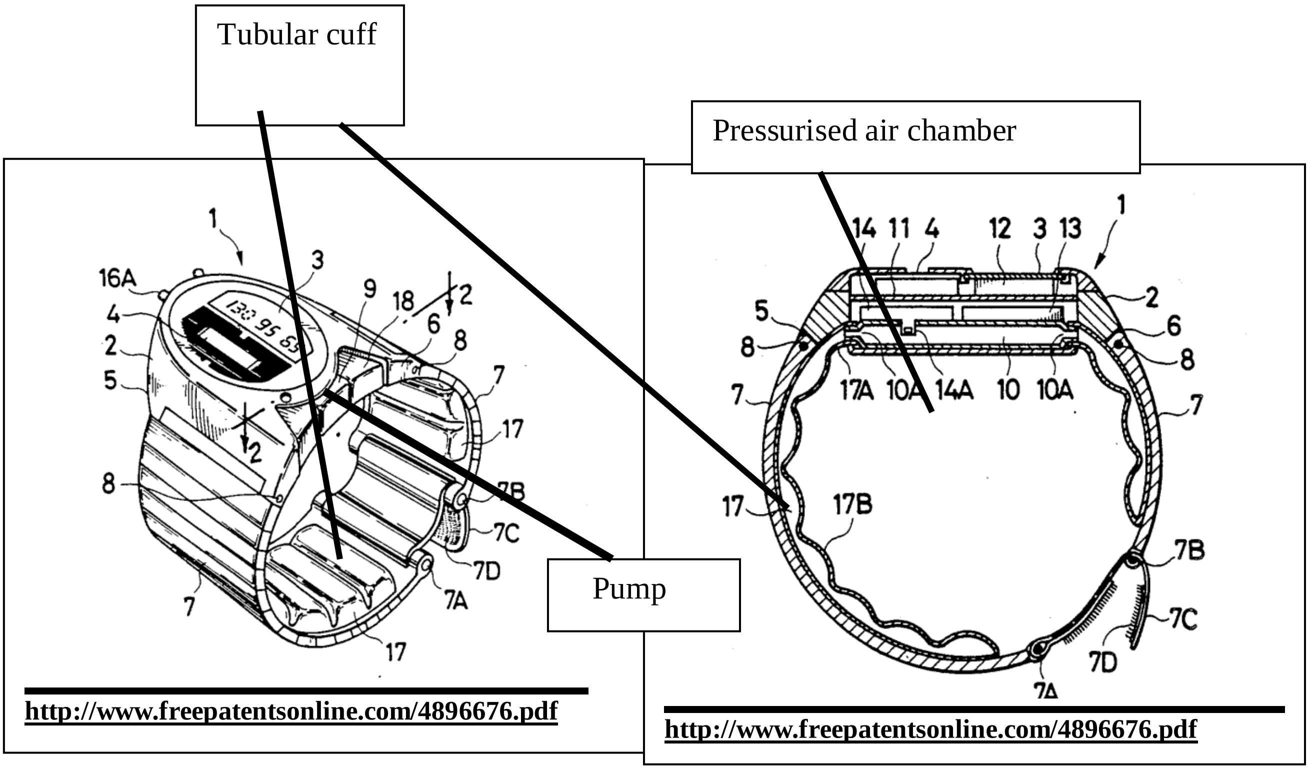


Fig. 4.1 (b) Small Blood-Pressure Watches with a tubular cuff (automatic inflation)

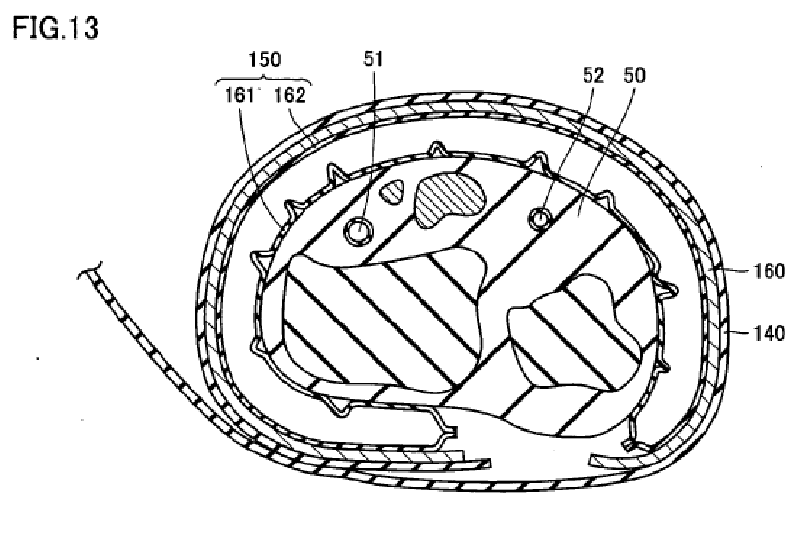
Air pump :

This watch has a built-in inflation system inside its metal band . The sensing techniques are similar to the big –wrist-BP devices that are available in the pharmacies , which are obviously oscillatory methods.

Basically these experiments are held to increase to some extent the accuracy and automation of blood pressure. A lot of factors influence blood pressure, some are of our knowledge and others are not. The 5 BP-changing-factors (chapter 4) are chosen because they occur continuously throughout the day, therefore, before any other factors, these 5 repeating factors have to be studied. Eating and hunger for example affects BP 2 or 3 times a day when the user is having lunch or other meals. The body posture and sleepiness, as well, are repeating factors.

Experiment Apparatus:

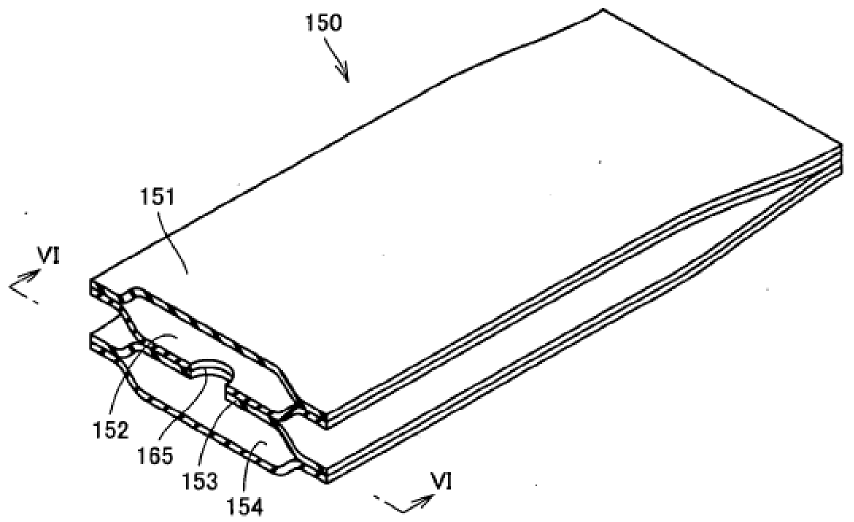
1) Two commercially available blood pressure BP measurement devices.
2) Stopwatch, to register the time intervals where the BP changing factor takes effect.



http://www.freepatentsonline.com/20060184054.pdf

Fig 4.1 (c) Inflatable device structure, 8/2006

FIG.5



http://www.freepatentsonline.com/20060184054.pdf

Fig 4.1 (c) Inflatable device structure, 8/2006

FIG.1

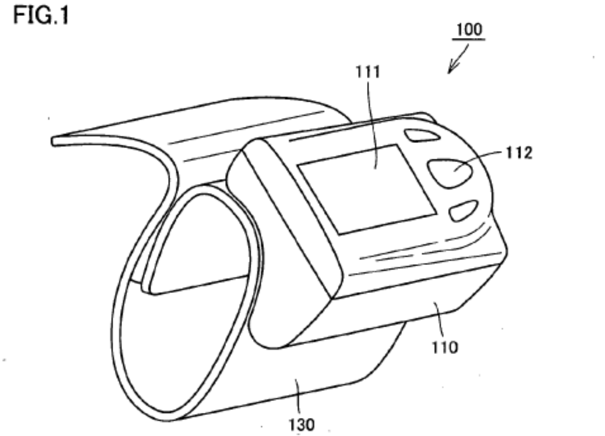


FIG.2

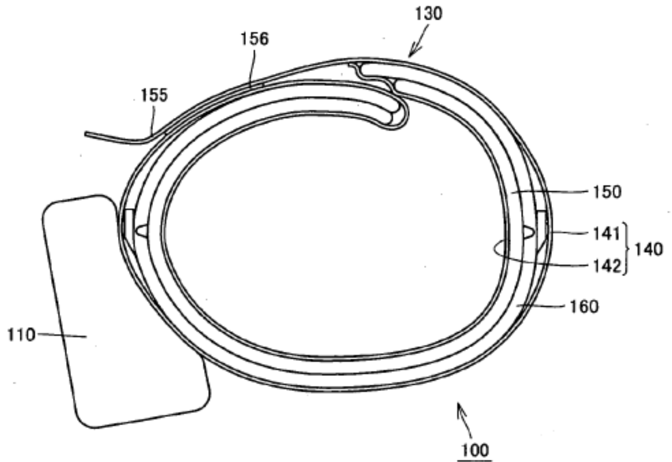
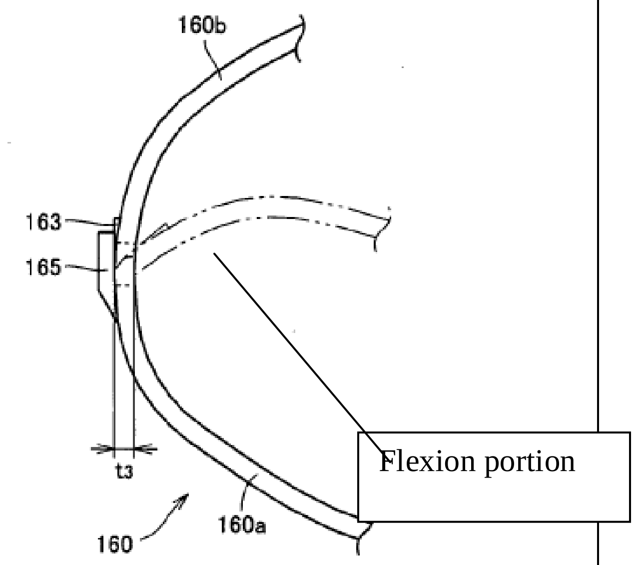


Fig 4.1 (d) Curling big wrist pressure devices, Oct / 2006

Fluid goes into the curl and push against the skin to exert the force necessary for the blood pressure measurement.



http://www.freepatentsonline.com/20060224069.pdf

Fig 4.1 (e) Curled Elastic Member

As a blood pressure changing factor is occurring, series of readings will be taken to check for the effect of this factor on blood pressure. To make these experiments as simple as possible, we should try to keep other factors constant. A very practical and easy method of doing this is applying the “factor under study” first thing in the morning, when there is a narrow margin of time for the other external unwanted factors to create an effect on the fresh blood pressure (these morning experiments are called Normal-effect experiments). The normal blood pressure value N should be around 120/80 in the morning, thus, if our “factor under study” has any effect on blood pressure the 120/80 value has to change.

4.2 Experiments for the Elimination of BP-Changing-Factors

Determining the participants “Normal level” of blood -pressure:

The normal level of blood pressure of the participant is the average level or the level that will always appear on the device screen when a proper reading is registered (usually in the morning before breakfast). It is also part of this range 90 - 135 / 50 - 90 , and it should be a consistent value for every person (closer to a fixed magnitude or value (e.g. 100 / 70) rather than a big range like the one above which is the normal range for all sorts of people).

Blood pressure should be a constant value whenever a measurement is taken.(on condition that no other factor should interfere).

4.2.1 Accuracy Limitations of the Experiments’ Readings and Results

Normal Effect Experiments:

The “Normal effect” experiments are much more accurate than the “Previous effect” experiments. Normal effect experiments starts with an initial value of blood pressure N. Usually, the normal blood pressure value N is filtered from other factors that might change it when it is early in the morning, when the user wakes up from sleep.

The normal effect experiment rise or drop in BP is calculated by determining the difference between the initial BP level and the final BP level after applying the BP-Changing-Factor (eating). (Difference in BP = BP final value – Normal BP level N).

Previous Effect Experiments:

Previous effect experiments starts with an initial value throughout the day where the BP has been affected by exterior unknown factors that we have no account for or knowledge about. Conducting this type of experiment is a necessity for some BP-Changing-Factors like the measurement of the effect of sleepiness on blood pressure, because the experiment has to start at night when the BP is already affected significantly by various BP-changing-factors that the user had come upon throughout the day. The previous effect experiment rise or drop in BP is calculated by determining the difference between the initial BP level and the final BP level after applying the BP-Changing-Factor(sleepiness). (Difference in BP = BP final value – Previous BP level).

Other accuracy limitations:

- The experiments are applied on one participant only.
- BP is determined using wrist-devices with limited accuracy.
- One reading will be the average of 4 consecutive readings.

4.2.2 Determining the Normal Blood Pressure Value of the Participant

Date	Time	Blood pressure fraction
Exp1 : (single reading) 16/5/2007	8 : 30	**125/85**

Exp2 : 17/5/2007	10: 04	120/84
	10 :12	124/84
	10:15	130/87
	10:25	126/84
		Avg : 125 / 84.75

Exp3 : 18/5/2007	10: 40	127/82
	10 :45	125/84
	10:50	123/88
	10:25	125/86
		Avg : 125 / 85

Exp4 :	11: 30 am	126/78

19/5/2007	10 :30	120/84
	11:35	126/88
	11:35	128/88
		Avg : 125 / 84.5

Exp5:

The author has visited a walk-in clinic to measure his blood pressure as a checking or confirmation method to the previous results ………the nurse made one reading using an accurate arm-measuring device. The measurement value was “125/84” which is very close to the results of the wrist-device.

Averaging the experiments:

Exp2 ------------------ Avg: 125 / 84.75

Exp3 ------------------ Avg: 125 / 85

Exp4 ------------------ Avg: 125 / 84.5

Exp5 --------- Nurse reading: 125 / 84

Total Avg: 125 / 84.6

Rounded for simplicity: 125 / 85

Normal pressure level of participant = 125 / 85 .

Now that we have got the accurate Normal level value, we can carry out the other experiments more confidently since that this value will be a kind of reference to other values determined by the experiments.

4.3 Experiments for Eating

Description of the Experiment:

Take the reading after a meal using a series of controlled (controlled experiment) periodic measurements (once every approx. 20 minutes) in order to draw the curve with these values. To find the eating pressure correction value subtract the measurement value from the normal level value N.

Values of Experiment 1. (Previous Effect Experiment) :

Before Eating,

3-consecutive-readings : (132/83, 126/80, 124/83) =127/ 82
4:30 4:30 4:35

After Eating,

5-consecutive-readings :(120/70, 124/71, 125/73, 124/77, 125/73) = 124/73
5:05 5:05 5:10 5:10 5:25

=> 127/82 minus 124/73 = 3/9

=> $\dfrac{\text{Systolic Decrease (3)}}{\text{Diastolic Decrease (9)}}$

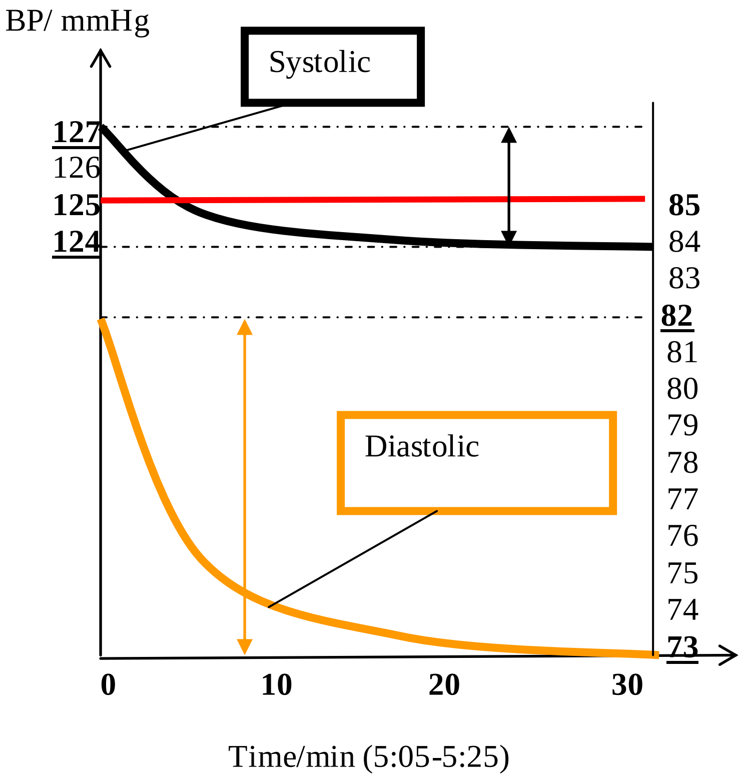


Fig.4.3a Graph of Exp1.

This graph shows that even when the systolic and diastolic values are away from the Normal BP (for some reason probably an external “BP changing factor” is interfering), despite of the external factors, eating food will make both systolic and diastolic values fall below the normal BP level, with different drop intensities but with a similar shape of graph as it is shown in the above (Fig 4.3a).

The blood pressure readings are so different within a minute because of the inaccuracy of the wrist measurement device used . This is why in these experiments an average of many consecutive readings will be registered as the value of a single reading at that particular time. In the previous page the average of 3 readings(132/83, 126/80, 124/83) was determined to be 127/ 82.

Values of Experiment 2 (Normal Effect Experiment: An experiment that starts from the normal BP level) :

4-consecutive-readings: (120/78, 131/74, 124/74, 116/74) =123/75

=> 125/85 minus 123/75 = 2/10

=> $\dfrac{\text{Systolic Decrease (2)}}{\text{Diastolic Decrease (10)}}$

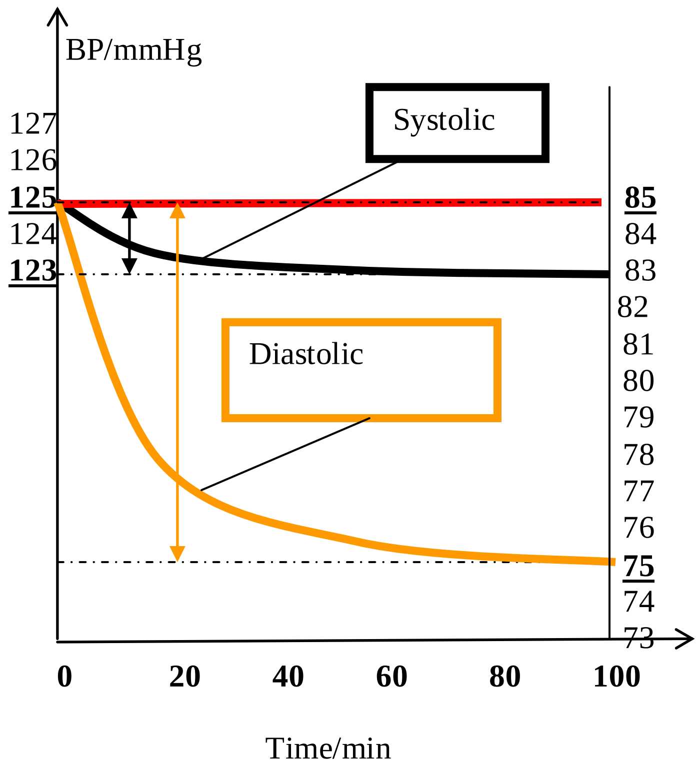


Fig.4.3b Graph of Exp2.

Values of Experiment 3 (Normal Effect Experiment) :

: 4-consecutive-readings: (118/73, 127/76, 117/81, 123/81) =121/78
4:15 4:15 4:16 4:17

=> 125/85 minus 121/78 = 4/7

=> $\dfrac{\text{Systolic Decrease (4)}}{\text{Diastolic Decrease (7)}}$

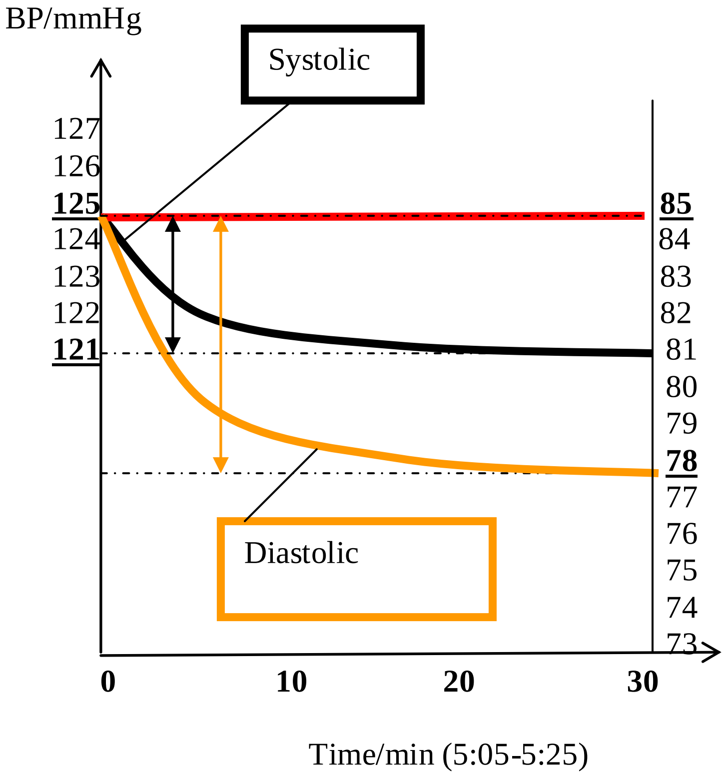


Fig.4.3c Graph of Exp3.

Eating will always drop the BP as it is shown on the above 3 graphs which confirms the same result. The BP will drop whether the starting point of BP is on the normal blood level (N), or whether it has been pushed away for some reason from the normal level (N). Both types will experience a drop of BP as a result of eating.

4.4 Experiments for Hunger

Description of The Experiment:

In this experiment the subject is left without food and breakfast passing the lunch time until 5 o'clock in the evening. This experiment was held to show the effect of hunger on BP and compare it to the effect that eating has on blood pressure.

Compensation Method :

To find the Hunger pressure correction value, subtract or add the experiment measurement value from the normal level value N.

Experiment 2 Values (Normal Effect Experiment) :

: 4-consecutive-readings: (103/54, 121/63, 130/67, 111/63) = 116/62
4:30 4:35 4:35 4:37

=> 125/85 minus 116/62 = 9/23

=> $\dfrac{\text{Systolic Decrease (9)}}{\text{Diastolic Decrease (23)}}$

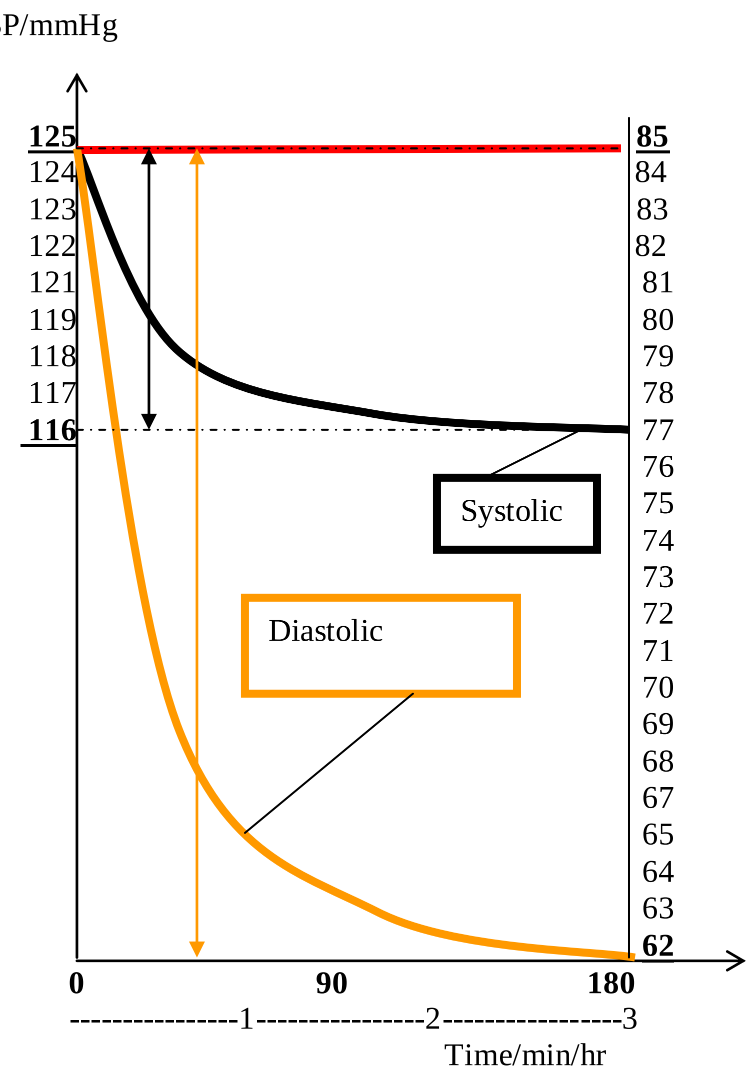


Fig.4.4 Graph of Exp2.

The shape of a hunger graph is almost the same as eating but the magnitude of drop is different. The effect of hunger on the human BP is much higher than that of eating (hunger has approximately double the drop in BP that eating exerts on the body). In particular, what makes all that difference in the results of hunger and eating is the diastolic recording of hunger where BP had fallen from 85 till 62, recording the maximum drop of BP of all the 5 experiments. This value is also the maximum change of BP of the 5 experiments.

4.5 Experiments for Sitting and Standing

Description of the Experiment:

The subject is asked to sit and stand continuously so that BP readings will be registered at every sit and at every stand. The time interval allowed between sitting down and standing up is approximately 5 minutes to give sufficient time for the BP to level up and take its new value.

Experiments Values:

Time	Blood Pressure	Sit or Stand	Drop or rise value
12:15	114/85	*standing*	**none - first value**
12:20	123/86	**sitting**	increase 9/1
12:25	116/76	*standing*	decrease 7/10
12:30	122/78	**sitting**	increase 6/2
12:35	116/74	*standing*	decrease 6/4
12:40	125/83	**sitting**	increase 9/9

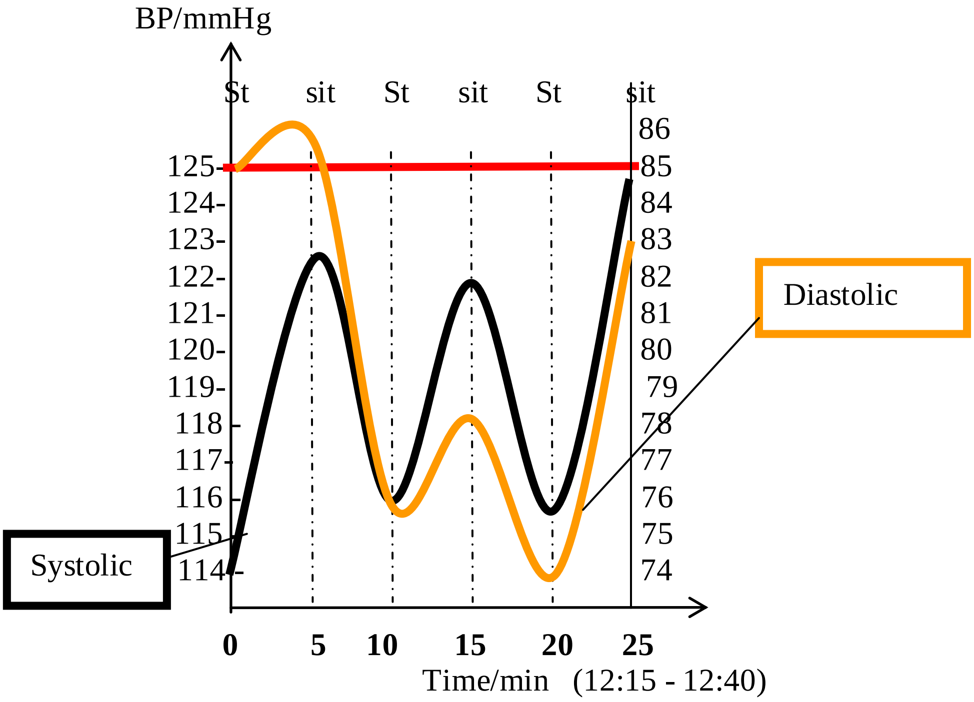


Fig.4.5 Graph of sitting and standing Exp.

The graph shows that there is a significant rise and drop in BP as the user is sits or stands up. The rise or fall of pressure takes an exact amount of 5 min for the complete rise or the complete fall. The experiments readings were taken consecutively. It seems that the constant actions of standing and sitting had affected the overall BP of the experimenter and made it go below the normal level (125/85) , as it shows on the above graph , which means that the constant and consecutive standing and sitting will have the same effect as walking which lowers blood pressure as well. That is , because the actions of standing and sitting where repeated many times , the body is now experiencing a sort of hard muscular effort , similar to the effort made by the body when a person starts to walk fast and which also made the graph drop below the normal level(red colour line).

The sitting and standing experiment recorded the most vigorous rise and fall of BP of all the experiments that is held in this study.

4.6 Experiments for Back Angle

Description of the Experiment:

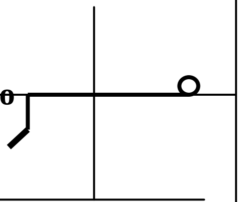
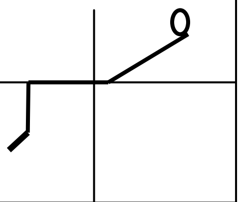
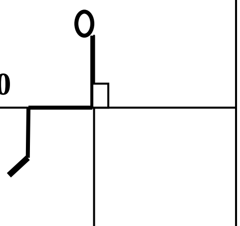
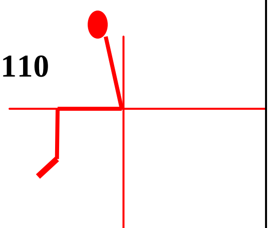
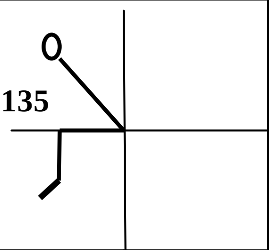
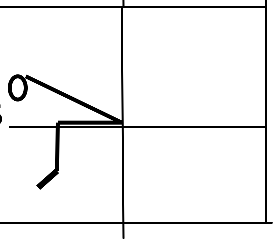
Definition of the factor**:**

This factor (back angle) is studied to give ill people, which are sleeping most of the time in bed with their back angles widened up with the level of their bed, the chance to read their BP without having to get up and sit. Back angle is the angle that shows clearly when a person is sitting on the chair (approximately 90 degrees), and which disappears when the same person lies on bed (180 degrees). Thus differences in these angles affects and changes BP dramatically.

In this experiment, BP readings are taken at variable back angles (shown below in table). The experiment emphasises on changing only the back angle of the subject without altering other postures as this can influence the values significantly. Enough time(15 min) is allowed between each and every angle readings as it was noticed that the body needs some time to forget the effect of the previous back inclination.

Experiment values :

Table. 4.6 Different back angles produce different blood pressure values.

Readings	Avg.of Readings	Angle
106/64 **100/60** **104/63** **110/65**	**105/63**	**zero** 
115/78 , **114/72,** **114/78**	**114/76**	**45** 
124/80 **120/80** **120/80**	**121/80**	**90** 
124/86 **124/80** **121/83** **125/83**	**Normal 125/85**	**110** 
127/88 **126/87** **127/91** **132/92**	**128/90**	**135** 
128/93 **126/90** **129/90**	**128/91**	**155** 

Recommendation:

This factor supports the QFD first and most important requirement "solutions for Old-age-problems". Back angle automation solves a problem that is present in most BP devices available in pharmacies which is the restriction to a back, hand, elbow, and arm level posture. This restriction posture will make BP measurement impossible for old and ill people which are resting in bed most of the time and can't even sit or bend their backs.

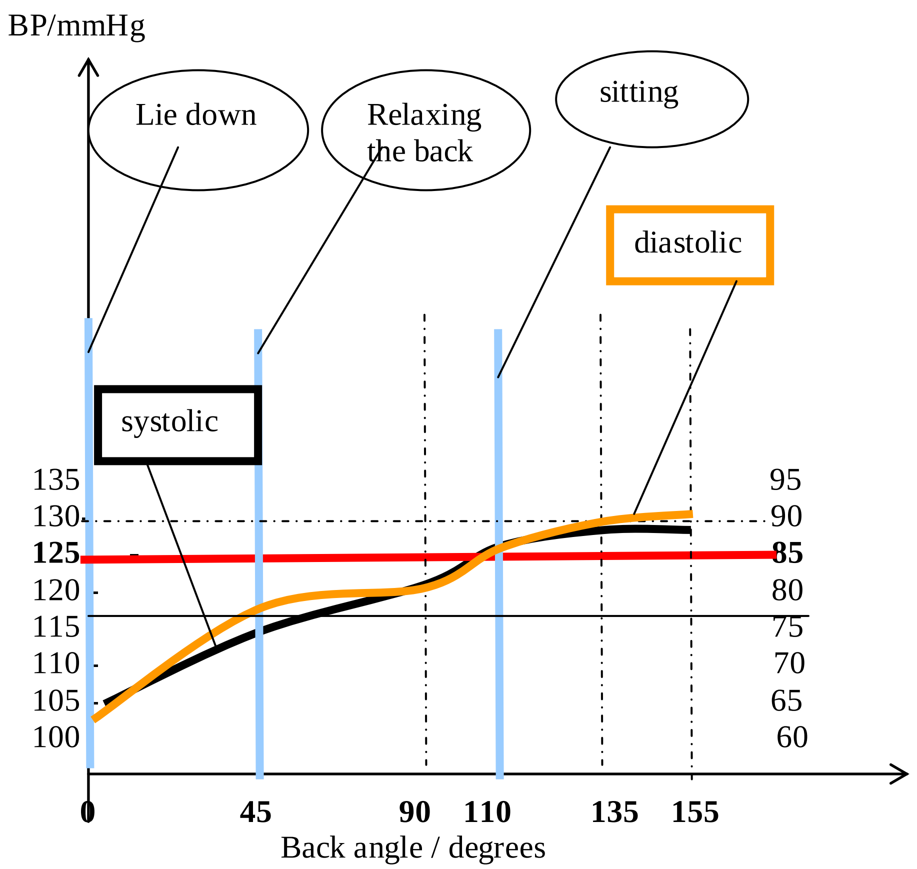


Fig. 4.6 Graph of back angle Exp.

We can notice clearly in the above graph, a proportionality rule which proves that as a laying person starts to bend his back towards his legs his BP pressure starts to increase with the bending until it reaches a value of 128/91 when his head is nearly touching his knees. The explanation of this is very obvious. When the user is laying down on the bed the heart will easily pump the blood to the entire body since that in such postures the whole body will level up with the heart. In other wards, the heart will not have a hard time pumping blood to body organs that are higher in level from the ground thus the heart has to oppose gravity and create an upward force. This force combined with the force of gravity will give the blood a specific pressure value which is higher of that of a laying person. On the other hand, this experiment shows that a bending person experience a greater BP than a normally sitting person, this is because during bending blood arteries and veins are squeezed due to the steep curve in the bending region at the back this will create a jam in blood transport creating high blood pressure. The results of the "sitting and standing experiment" supports this experiment since that its graph shows that a sitting person has a higher BP than a standing person where in the case of the standing person the blood will naturally fall from the heart needing no force to pump it downwards while in the case of a sitting person the blood will initially have a natural fall but will soon meet a small bending lower part of the back (at a 90 degrees angle) and will also meet another bending at the knees. These two bending form the normal posture of a sitting person.

4.7 Experiments for Sleepiness

Description of the Experiment:

As the night begins, the body is demanding sleep and sleepiness occurs, at this stage, start taking readings to draw the graph of no-sleep/sleepiness effect. The readings are measured every hour starts from 6:00 o'clock in the evening and ending at 6:00 in the morning (when the body is exhausted from lack of sleep and where sleepiness is maximum).

Values of Exp1 (Normal Effect Experiment):

: 4-consecutive-readings: (116/81, 118/81, 118/80, 120/80) =118/81
11:10 11:15 11:15 11:16

=> 125/85 minus 118/81 = 7/4

=> $\frac{\text{Systolic Decrease (7)}}{\text{Diastolic Decrease (4)}}$

Graph of Experiment:

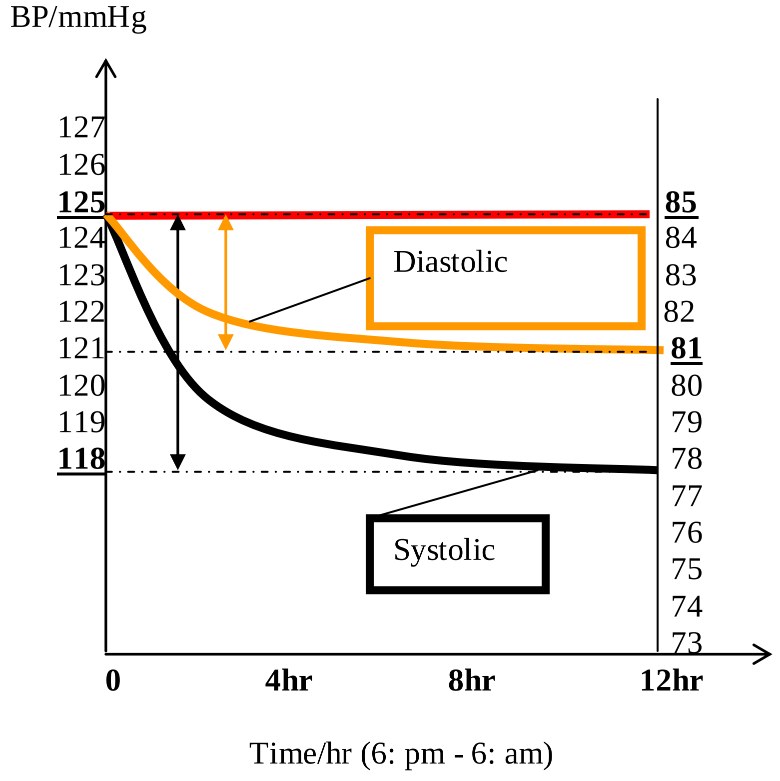


Fig. 4.7 Graph of sleepiness experiment.

Recommendation:

This factor supports the QFD first and most important requirement "solutions for old-age-problems". Doctors can check patients BP while asleep. These experiments are highly recommended.

In this experiment the BP has dropped below the Normal BP level N. The drop of the systolic is double the diastolic. Between 8:00 o'clock and 12:00 o'clock the systolic and diastolic BPs had ceased to decrease

Experiment Values:

: 5-consecutive-readings: (126/78, 124/76, 117/70, 123/73, 121/71) = 122/74
4:00 4:15 4:17 4:20 4:25

: 4-consecutive-readings: (121/70, 125/70, 122/76, 100/70) = 117/72
4:40 4:43 4:45 5:00

Subtract the sleepiness BP value from the previous pressure value to give you the sleepiness correction pressure value.

=> 122/74 minus 117/72 = 5/2

=> $\dfrac{\text{Systolic Decrease (5)}}{\text{Diastolic Decrease (2)}}$

4.8 Summary

Chapter 4 shows the realistic results of this study. First, the results of the blood pressure (BP) experiments are determined. The effect of 5 factors that influence BP are established using graphs, where the rise or fall in BP, for each factor, is shown on the graph and the difference in BP levels are measured and registered. The experiments have studied five factors only, and were conducted on one person only because of the scarcity of time and resources.

Chapter 5 : Conceptual Design of Sensors and Automation of the Portable Health Monitoring System

5.1 Introduction

The results and values acquired in the previous chapter (chapter 4), should now be transferred to the processor of the product. So that readings will be compensated and automated even with the most awkward situations, when the user is taking his BP readings (eg. during walking). The system that is responsible for this compensation function is “The BP automation system”.

Definition of “The BP Automation System”:

The collection of sensors along with the watch processor which integrates their functions to detect the BP-changing-factors affecting BP readings, and to compensate those readings accordingly.

This means that if the user wants to measure his BP after having lunch, his measurement can be as accurate as it is when waking up in the morning, only if no other factors interfere. Similarly, if the user wants to measure his BP late at night when feeling asleep his blood pressure might be very normal. The uncertainty in BP measurements originates from extraneous factors that ruin the readings, thus, eliminating these factors will yield more accurate readings of BP.

In this chapter, we are going to insert the sensors involved in “The BP Automation System” inside the watch body or inside a separate ribbon.

5.2 Detection and Elimination of BP-Changing-Factors

BP measurement can only be made when certain conditions are satisfied like posture, timing, movement (the body has to be remaining still during measurement). Therefore, the added automation features should give the user full freedom of measurement anytime and anywhere, making it a 24 hour wearable and usable device.

5.3 Types of Sensory Systems and Sensors' Detections of BP-Changing- Factors

Now we are going to design a blood pressure automation system that will enable the user to read his BP anytime and anywhere. This is a 24 hour BP monitoring system, which enables the user to read his BP in awkward situations (e.g. during walking, or during eating). In order to do this, we have to establish a sensory automation system that will support the experiments, detecting the rise or drop in pressure that these factors exert on blood. Eliminating these factors will filter blood pressure readings and give us the real blood pressure values.

1) The detection of a change in <u>graph pattern</u> of BP (Numerical values, shapes, and directions of curves).
: By means of a normal size (24 hrs worn watch) with a built in processor for graph pattern comparisons.

2) The detection of <u>Heart pulse</u> change: By means of a very small pulse sensor that is capable of comparing different heart pulse speeds by sensing heart pulses from the hand wrist area.

3) The detection of a change of <u>Accelerometer</u> values: By monitoring the different speeds of the accelerometer, which means different types of hand movement originating from different actions by the user.

4) The detection of a change of Gyroscope values: By monitoring rotations and position orientations, and their speed, which describes what the user might be doing.

5) Combined detection of the previous methods :

By means of a processer that compares and combines information e.g.: accelerometers and gyroscopes in the watch can tell whether the patient is eating , from the periodic back and forth movement of his hands(with specific acceleration distances and gyroscope inclinations).

Table. 5.3 Combinations of sensors involved for each experiment type.

	Heart pulse sensor	**accelerometer**	**gyroscope**	**Digital Information pattern**
1) Eating		**yes**	**yes**	**yes**
2) Standing or Sitting		**yes**	**yes**	**yes**
3) Back angle		**yes**	**yes**	
4)Walking	**yes**	**yes**	**yes**	
5)Sleeping	**yes**	**yes**		**yes**

5.3.1 Compensation Method

This method will allow the device to correct the BP readings at any instance under the detected interval of time. The detection sensors will inform the device about the duration of time where the “BP-changing –factor” is occurring. The registered extra value of the factor (in the device memory) will be proportionally subtracted.

Example (Unreal values) : The compensation of sleepiness to reach a more accurate BP value.

Sleepiness is detected when the heart pulse sensor records a value of 40 pulses/min. A signal will be transmitted from the heart pulse sensor to the processor to subtract the effect of sleepiness value which is already stored in the processor as the result of the sleepiness experiment (10 points decrease of the systolic, 10 points decrease of the diastolic.)

Thus, any factor that will be included in this study has to have a detection scheme through a sensor or sensing method so that the compensation of readings will be calculated along with the measurement.

<u>Factor Duration Detection Method</u> :

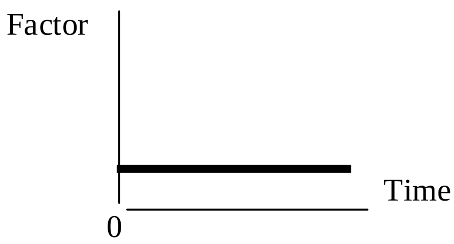


Fig. 5.3.1a Factor duration parameter.

The watch can differentiate between different “BP-Changing- Factors” by their durations intervals. In other words, each BP-Changing- Factor takes a certain interval of time to change the previous BP value. Some factors , as we are going to see, needs 5 minutes to raise the BP level upwards, others takes hours(sleepiness factor).

Factor Degree Detection Method :

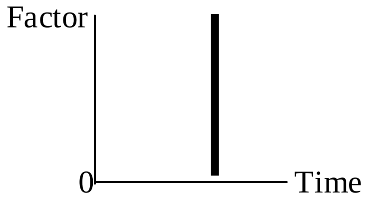


Fig. 5.3.1b Factor degree parameter.

This type of detection method emphasises on the magnitude of change, usually the y-axis rise or drop in BP level. That is, different factors can affect blood pressure BP in different magnitudes, thus each factor can be identified or detected by measuring how much it had pushed up the BP level.

An example of a steep rise in BP is the “sitting factor”, which is a similar case to (Fig. 5.3.1b). In fact, the most accurate detection method is Fig. 5.3.2b (p131), where the exact shape of the blood pressure graph (time against intensity of factor) is stored in the products memory. That is, the graphical information of the 5 experiments to come will be stored in the product, so that the processor can identify the factor when it occurs and subtract it (for example eating has a unique graph, this will inform the watch that the person is eating from the progress of his blood pressure monitored by the BP sensors attached to the watch). Knowing that the BP-changing-factor (eating) is interfering at a certain moment, the watch will automatically subtract its effect magnitude, whether it’s an increase or a decrease in BP to always keep the users BP to its normal regions.

5.3.2 Graph Direction Detection Method

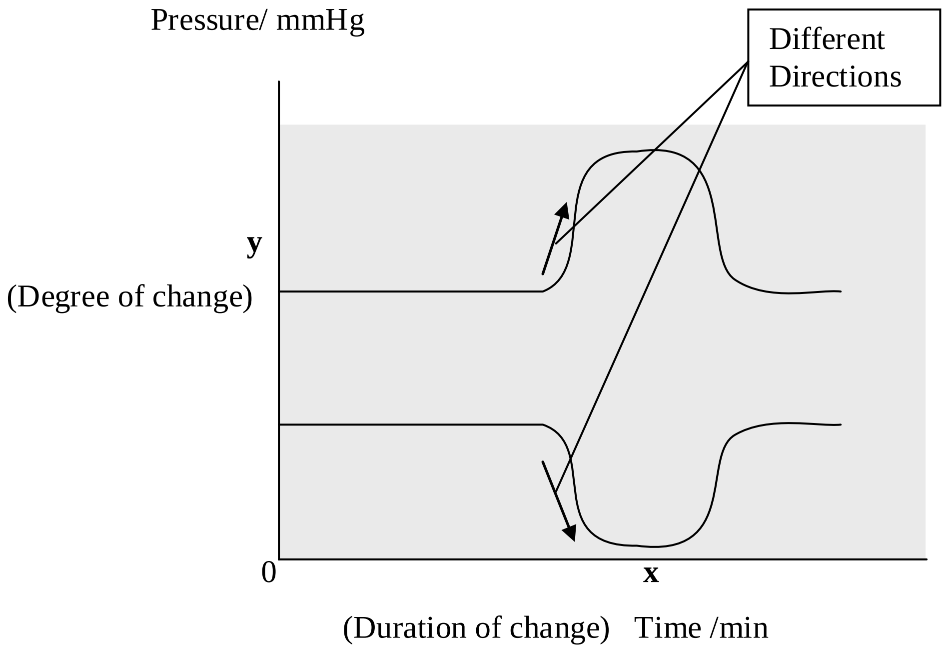


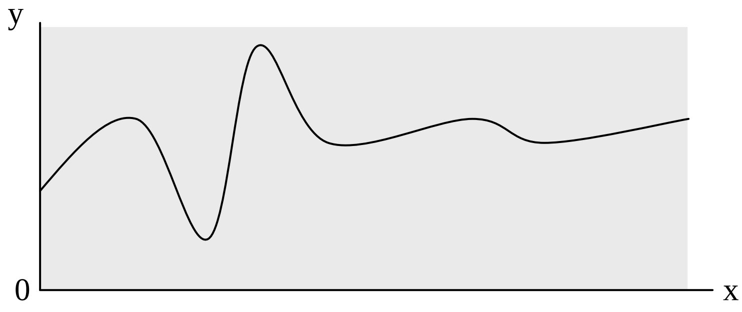
Fig. 5.3.2a Different graphs with different directions of change.

The direction of the graph means the increase or decrease of BP by the watch at a specific interval of time. It is quite similar to the “BP Graph Pattern Detection Method” but different in the fact that it can detect the pattern of the graph in an interval of one and two minutes, unlike the graph pattern detection that might take hours to draw the graph which summarises the effect of a certain factors on BP.

As it was mentioned before, the criteria which the processor will detect are not many (directions, numerical values, shapes of curves). The example above is closest to an experiment that was conducted (about the effect of walking and walking fast on BP levels). The experiment showed interesting results which is similar to the above graph. During walking the systolic pressure tends to rise leaving behind it the diastolic pressure. On the contrary, the diastolic pressure gradually starts to drop in the opposite direction of the systolic. This type of graph is very unusual, since that the systolic and diastolic graphs will usually rise and drop together.

“ BP Graph Pattern” Detection Method :

(Degree of change)Pressure/ mmHg



(Duration of change) Time /min

Fig. 5.3.2b Graph-shape digital detection.

The shape of the graph can be very steep :

Pressure / mmHg

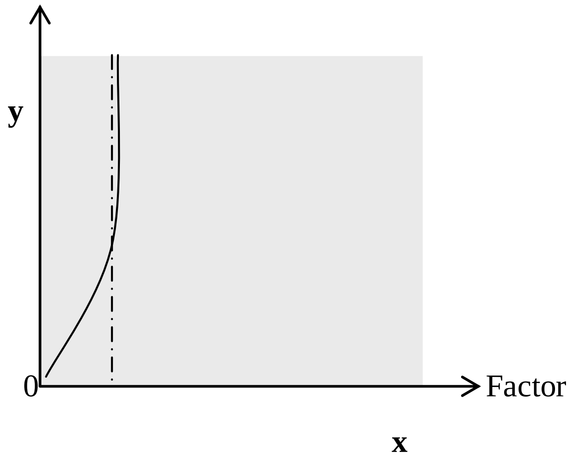


Fig. 5.3.2c An example of a steep BP graph.

There are many factors that elevate BP, like sitting or bending the back (reaching for the knees). This graph shows how factors can elevate the BP in a steep way. The difference between the sitting effect on BP and the “forward-back-bending” effect is that the back bending elevation of BP is not as sharp and steep as the sitting effect. Even when the experiment was repeated with more bending of the back, there was no big effect on the rise of the graph, instead slight and gradual elevations where recorded.

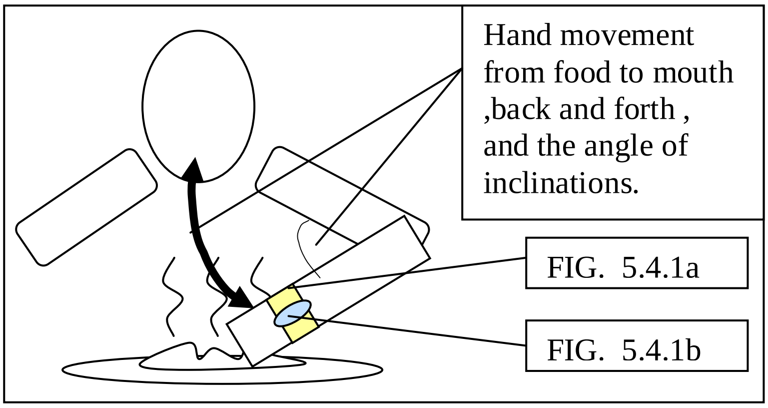
5.4 The Selection of Sensors That Should Detect the BP-Changing-Factors

Now that we have obtained the results of the experiments of chapter 4, we will store the results in the memory of the processor as values that affect blood pressure. These values will be compensated automatically when the sensors of “the BP automation system” will judge that one of the experiments’ factors is occurring.

5.4.1 Detection Methods Used For Eating

	Combinations of sensors involved for Each experiment type.			
	Heart pulse sensor	accelerometer	gyroscope	Digital Information pattern
1) Eating		**yes**	**yes**	**yes**

1) Arm movements of equal distances (using accelerometer and gyroscope). Similar distances will always be recorded, whether the food is served in a plate on a table or while standing (sandwiches).



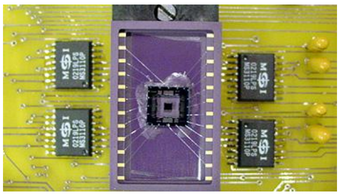


Fig. 5.4.1a : MEMS accelerometer.[53]

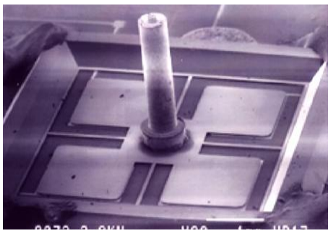


Fig. 5.4.1b : MEMS gyroscope.

2) Detection of a graph pattern and digital information (drop in BP) after half an hour.

> " *Postprandial hypotension (low blood pressure) occurs 30–75 minutes after eating. Because digestion sends a great deal of blood to the intestines."* (http:www.wikipedia – hypotension).

This paragraph from Wikipedia Encyclopaedia, along with the results of the experiments, has proven that pressure will decrease within ½-1hour after eating.

Graph Direction Detection Method :

Eating : decrease / decrease

5.4.2 Detection Method for Hunger

The effect of hunger will start from the morning if the watch detects an absence of the back and forth movement of the hand, meaning that the user is not getting any food. Starting from the morning, the watch will count the hours of hunger experienced by the user. The watch will gradually begin to compensate the effect of hunger value revealed by the experiments in chapter 4.

Graph Direction Detection Method:

Hunger : decrease / decrease

5.4.3 Detection Method for Sitting and Standing

	Heart pulse sensor	accelerometer	gyroscope	Digital Information pattern
standing or sitting		**yes**	**yes**	**yes**

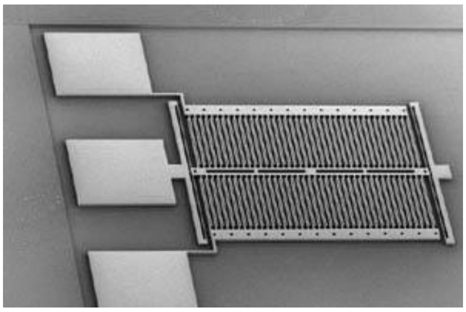


Fig. 5.4.3a Micro accelerometer. [54] (http://www.wtec.org/loyola/mcc/mems_eu/Pages/Chapter-5.html)

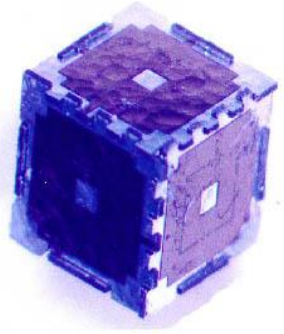


Fig. 5.4.3b "3-D-Gyracc" under development.

The detection of a vertical upward or downward movement of the body, using accelerometers and gyroscopes and combined with a rise or drop of the BP values (using "graph direction detection" by the watch processor) together implies that the body is experiencing sitting or standing.

In other words, if the user sat on the chair his blood pressure will rise upwards significantly (about 6 degrees) and at the same time the gyroscope will show a downward vertical movement.

Graph Direction Detection Method :

Sitting : increase / increase
Standing : decrease / decrease

5.4.4 Detection Method for the Back Angle

	Heart pulse sensor	accelerometer	gyroscope	Digital Information pattern
Back angle		**yes**	**yes**	**yes**

The automation system will wait for the first sign which proves that the back angle is moving, which is the slow acceleration detected by the accelerometer combined with a slow rotational movement registered by the gyroscope. Nevertheless, such movement and inclinations could be generated from the hand itself and not the back; this is why the automation system will be waiting for a third piece of information. The system will be waiting for the “digital information pattern” which will show if the change in the gyroscope angle is compatible with the BP reading, since that the relationship between the two will be previously stored in the system.

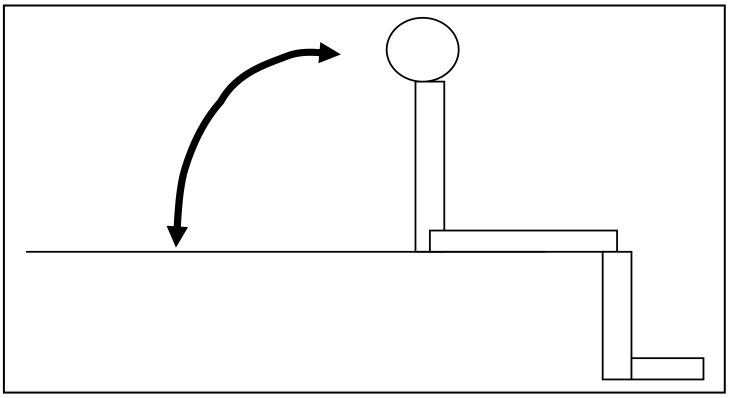


Fig. 5.4.4 90 degrees angle of the back

Graph Direction Detection Method:

Bending the back forward : increase / increase
Bending the back backward (relaxing the back) : decrease /decrease

5.4.5 Detection Method for Sleepiness

	Heart pulse sensor	accelerometer	gyroscope	Digital Information pattern
sleepiness	**yes**	**yes**		**yes**

1) First of all, heart pulse rate drops to the sleeping heart pulse rate which is much lower than the normal rate. This low rate which occurs during sleep will be detected by the pulse sensor (built-in inside watch).

2) A sleeping person moves from time to time. “Sleep-movements” (once per 10-15 min) occur much less frequently than “awake-movements” (once per 1-10 seconds).The Accelerometer digital information with a minimum interval of time of 30 min will show the drop in the movements level associated with sleep. This detection scheme reconfirms the basic detection method (sleep pulse detection), but it cannot be a stand –alone detection method.

Graph Direction Detection Method :

Sleepiness : decrease / decrease

5.5 Design Proposals and Improvements of the Selected Medical Techniques of Chapter 4

The purpose of these improvements is to alter the already existing sensory techniques converting them to be more compatible with a portable watch, since the techniques or technologies are designed in the first place for applications which are not intended for portable devices. In addition, harnessing the sensory techniques to convert the process of BP measurement from a stationery process, where the user has to sit still during measurements, to a mobile process to allow him to monitor his BP during walks and free movements.

The QFD have revealed that these are the most important features that should exist in the main medical sensory system to be used by the old age people to check their health status.

The Most important features:

1) Total weight and dimensions of the sensor. (Normal size/MEMS)(222 importance weight)
2) Sensor position accuracy (208 importance weight)
3) Sensor integration (153 importance weight)

5.5.1 Total Weight and Dimensions of the Sensor. (Normal size/MEMS)

The QFD study results show a great need for the MEMS technology **(222 importance weight)** to be implemented in this product.

5.5.2 Sensor Position Accuracy (208 QFD importance weight)

This design solution is extracted from the design options generated by “the harmonic –unity” design methodology. We will be looking at the “harmonic –unity” method later in this chapter.

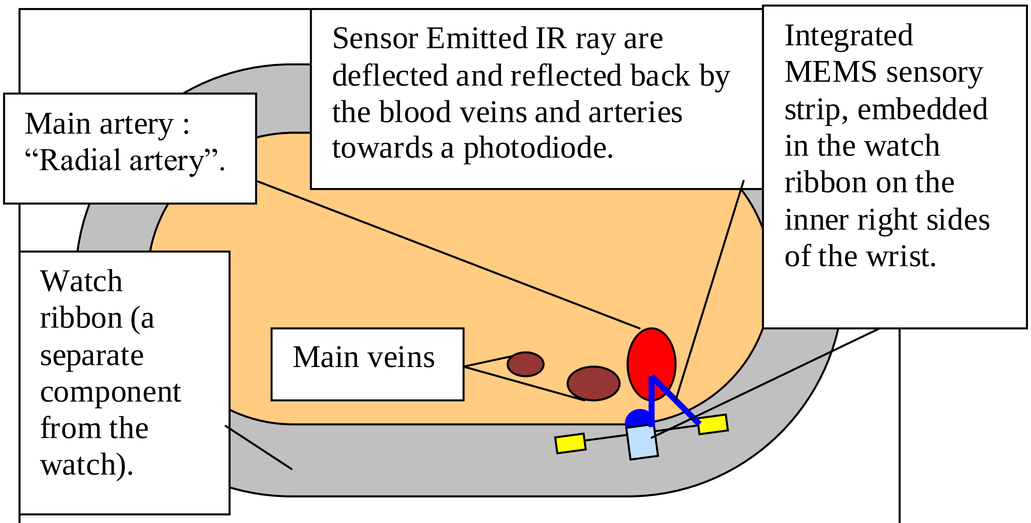


Fig.5.5.2 Ribbon surrounding wrist flesh : with the sensory systems situated under the main wrist artery and veins.

Fig. 5.5.2 Will be produces further in Fig. 5.5.3a,b.

The watch ribbon function is to fix the integrated MEMS sensors beneath the main veins and artery of the wrist. The watch ribbon is a separate piece from the watch. It should be transparent to allow the emitted infrared rays to penetrate outside the ribbon into the flesh and veins and arteries.

The Integrated MEMS sensor Strip contains:

1) **Infrared Thermometer** which lies in the center of the middle sensor, along a heat-conserving vacuum gap to allow accurate body temperature measurement.
2) **Piezoelectric sensor** for BP contact measurement and heart pulses rate measurement (for the detection of BP-changing-factors), piezoelectric sensors are distributed around the main wrist artery.
3) **Oxygen/CO2 IR sensors** contained in the middle sensor, these sensors include infrared rays emitters and photodiodes receiving these emitted rays measure oxygen and CO2 concentrations in the blood stream.

4) **Photodiodes** distributed around the main wrist veins, the photodiodes receive reflected infrared rays and visible red light to measure CO2 and oxygen respectively.

5) **Blood density IR sensor** contained in the middle sensor to check whether the user's blood has a normal density value.

5.5.3 Sensor Integration (153 QFD importance weight)

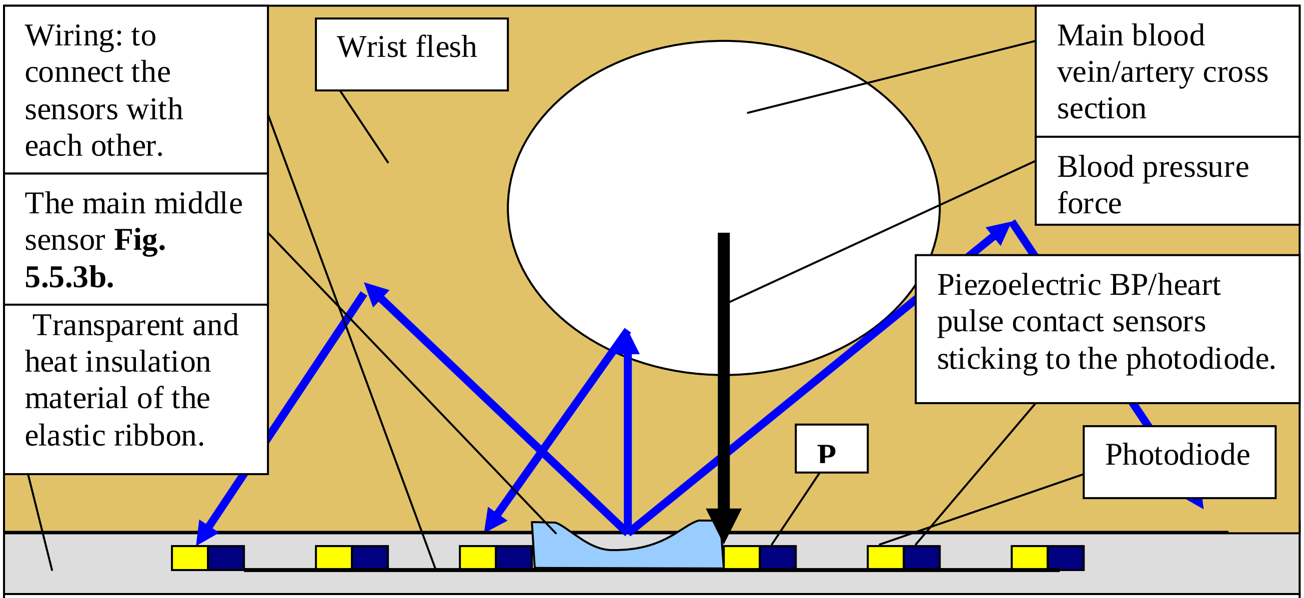


Fig. 5.5.3a Main Integrated wireless Sensor Strip (MEMS- length=2 cm) embedded in the ribbon.

(Fig.5.5.3a will be produced further in Fig.5.5.3b)

The sensor is integrated in a "strip shape" (Fig. 5.5.3a) to give a 1 cm freedom of positional error. In the middle of the strip lies the main middle integrated sensor (light blue) which combines more than one MEMS sensor in the same chip. The other sensors dispersed on the sides of the main sensor are the photodiode (yellow) which receives the IR reflected ray and converts it to a voltage that is proportional to the intensity of the received partial or complete IR ray. The photodiode is dispersed along the sides to trace the reflected or refracted rays if they are to be directed away from the main vein area. These reflected rays show how much blood is saturated with oxygen or CO2 according to their intensity which is compared with their intensity before penetrating the blood. The other sensor which is combined with the photodiode is the contact piezoelectric sensor (dark blue). This sensor is dispersed along the strip to give the most accurate possible BP reading by choosing the reading of the contact sensor nearest to the main vein. In other words, there are 7 contact sensors positioned along the strip, each of these sensors will have a different BP reading, since that the closer to the vein area the higher is the blood pressure reading.

The rigidity that the vein will exert on the flesh when experiencing high blood pressure will be transferred to the skin through a perpendicular force which is maximum at the centre of the vein cross-section acting down and perpendicular to the vein through the flesh and to the surface of the skin. In Fig. 5.5.3a, the nearest sensor to the BP force is sensor **P** as it is shown on the diagram. The watch will pick the highest readings of all the contact sensors (by the built in processor). The BP values detected by the sensors will be wirelessly sent to the watch for comparisons.

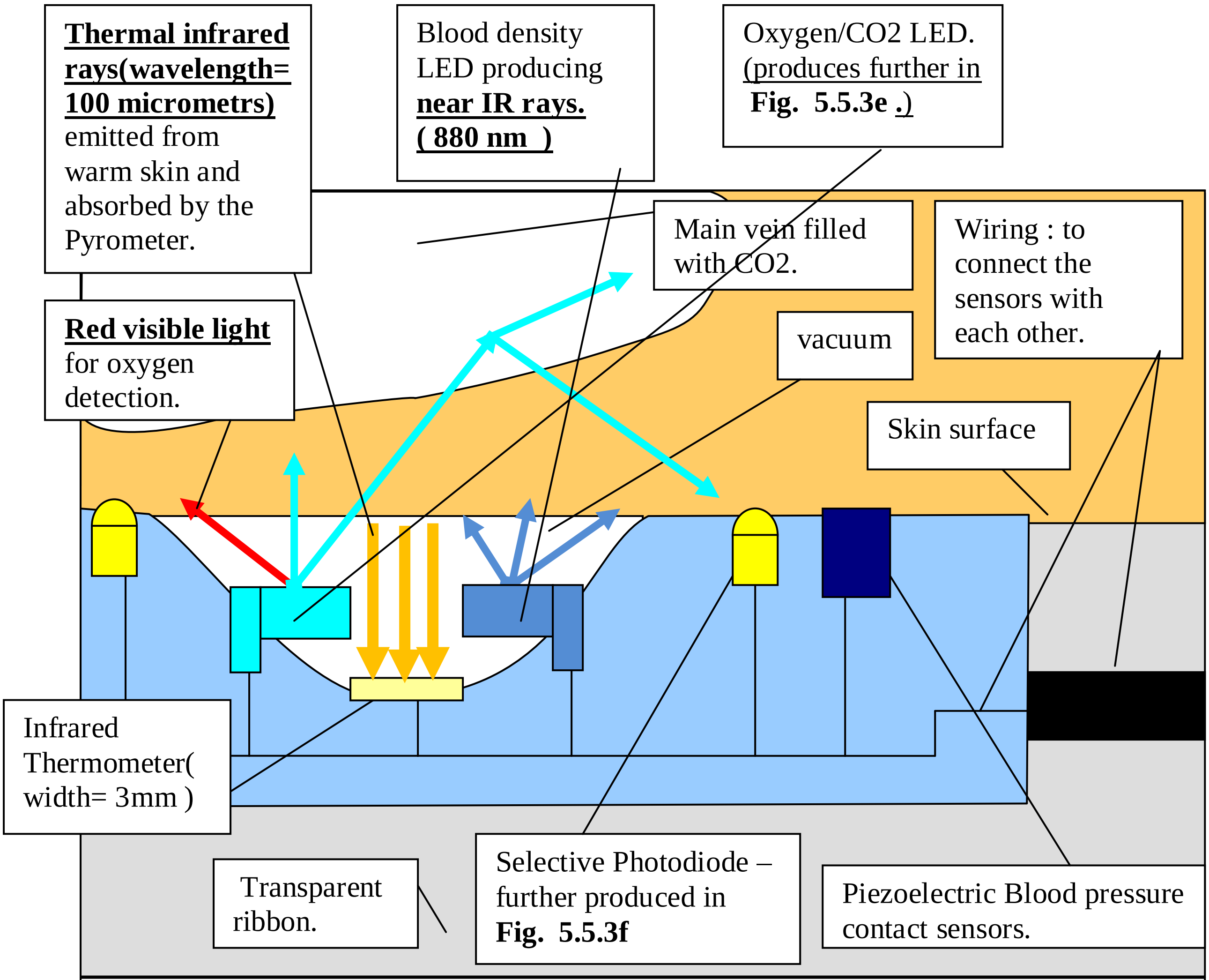


Fig. 5.5.3b The main middle sensor (width = 1cm).

Main Middle Sensor:

The IR ray coming from the main middle sensor is diverged (90 degrees divergence thickness angle) to allow the rays to reach the main vein even if the ribbon is miss positioned from the vein area. The vacuum gap conserves body heat for the downward thermometer to measure. The gap also provides a distance for the thermal skin-radiated rays (absorbed by the thermometer) to travel through, so that the D: S ratio can be calculated. (D: S is mentioned in chapter 3, infrared literature) [55].

The Oxygen/CO2 detection method is as follows:

The sensor doesn't know for sure the exact and accurate position of the main artery and the main vein. However, both the red visible light and the infrared rays will be reflected back on the ribbon after penetration through skin, nerves, main artery blood, main vein blood, capillaries blood, and fat. The photodiodes dispersed with equal distances on the ribbon will register variable values for oxygen and CO2 quantities detected inside the wrist flesh. The photodiode registering the maximum value of oxygen should be directly above the artery, and the photodiode registering the maximum value of CO2 should be directly above the vein. This is because there is a 3 mms distance between each and every photodiode sensor. Therefore, the main artery and main vein can be clearly identified and distinguished. Since that next to each photodiode there is a piezoelectric sensor, the photodiodes giving highest values of oxygen and CO2 will trigger the piezoelectric sensors next to them to measure the systolic pressure from the artery and the diastolic pressure from the vein. The piezoelectric sensor next to the photodiode with maximum value of oxygen will measure the systolic BP, and the piezoelectric sensor next to the photodiode with maximum value of CO2 will measure the diastolic BP. [56], [57] Distributed Contact Piezoelectric BP Sensors :

Only the BP readings of the piezoelectric sensor nearest to the artery will be taken (usually, this is the reading with the maximum value). The artery is the vessel carrying the systolic wave which pumps the blood out of the heart and transfers oxygen to the body.

In addition of being a BP measurement MEMS device, the piezoelectric sensor has the ability to measure heart-pulse rates [58] since it is extremely sensitive to any force generating beneath the skin. The selected piezoelectric sensor is a “Stress and strain sensor”, mentioned in chapter 2. The sensor will detect the gradual push of the skin on the sensor originating from an expansion of artery diameter (because of BP). The sensor will also detect the heart beat rhythmic pulses on the skin level, coming straight from the heart through the arteries to the skin. The Integrated Electronics Piezoelectric (IEPE) technology, mentioned in the literature, allows the sensor to differentiate between flesh-embedded rhythmic forces and flesh expansion forces.

The piezoelectric nature of the sensor will allow it to convert displacement of the skin into electric current which can easily be measured. A crystal inside the sensor can generate current if force is exerted on its surface.

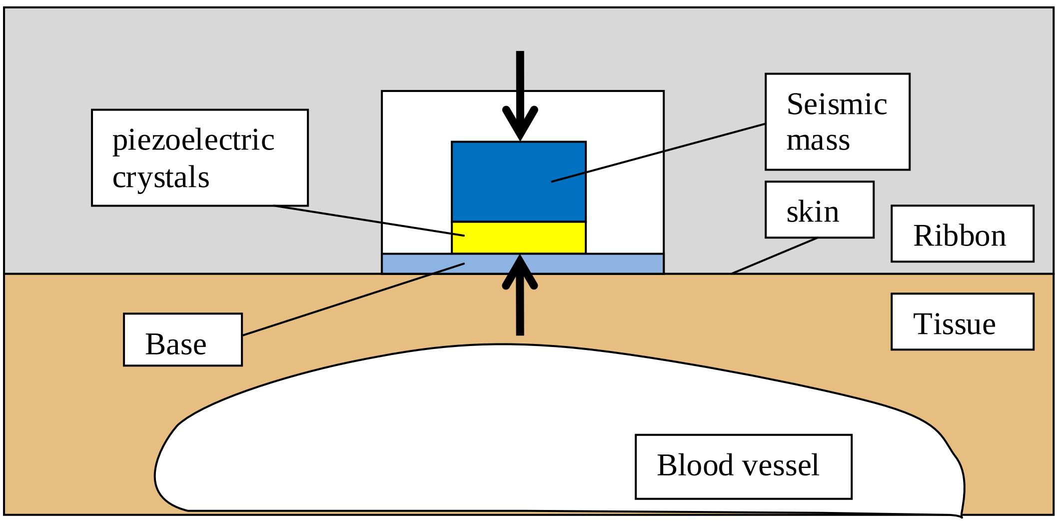


Fig . 5.5.3c Force piezoelectric sensor. [59]

As the BP will increase inside the wrist, the ribbon will absorb this force and exert it on the embedded sensor (above: 5.5.3c).

As it was mentioned at the end of the above paragraph, heading: **"The Oxygen/CO2 detection method is as follows"**, the piezoelectric sensor can distinguish between the main vein and the main artery only by the interference of the Oxygen/CO2 sensor (Fig. 5.5.3e: 2 pages below).

Infrared Thermometer :

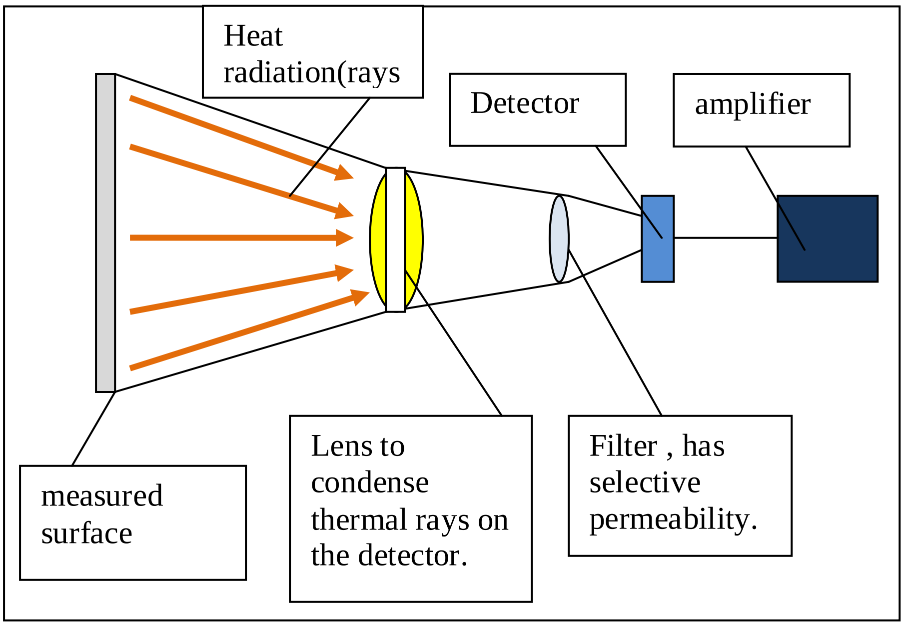


Fig. 5.5.3d MEMS Infrared Thermometer Diagram.[60],[61],[62]

The IR thermometer is situated (Fig. 5.5.3d)on the inner surface of the ribbon to be able to measure body heat, this is why the ribbon should be made out of an insulating material to conserve heat between the skin surface and the ribbon.
The IR thermometer should contain a convergence lens to focus heat radiations on a heat detector. The heat detector, like the blood pressure contact detector, is of a

piezoelectric nature. Inside the detector there are 2 surfaces, when exposed to heat, these 2 surfaces move apart from each other forming a piezoelectric effect, thus generating current which is proportional to the amount of heat received from skin surface. The IR thermometer should also have a filter to differentiate diffracted infrared rays of oxygen and density sensors from heat radiation. It should actually stop near-infrared light visible light (including red light) and allow only the penetration of thermal infrared rays. [63]

Advantages of Blood Density Measurement:

Statistics had showed that obese people and people with cholesterol problems have more dense blood than normal people. A Dense blood level means that the body is not in its best conditions. This is why the blood density sensor was chosen since that it is an indication of general health and can be an indication of high blood sugar (diabetes).

> *"Dense Blood can be a direct symptom of diabetes, although a patient with dense blood can be suffering from diseases or blood problems other than diabetes."*(Phone Inquiry – Doctor Ibrahim khaleel – USA – California)

Advantages of blood Oxygen/carbon dioxide level measurement:

Normal level of oxygen can mean that the user is in a perfect health condition. Low or high level of oxygen and carbon dioxide shows that something is wrong with the body, especially heart problems which are very common between the elderly users. Low oxygen level might also mean lack of nutrition or general body fatigue, therefore, oxygen measurement is a general or multi-health measuring method. The sensor is connected to the watch alarm so that if the oxygen or carbon dioxide level should exceed the normal values, the alarm will automatically warn the user.

Blood Oxygen level/Carbon dioxide Red/IR Sensor :

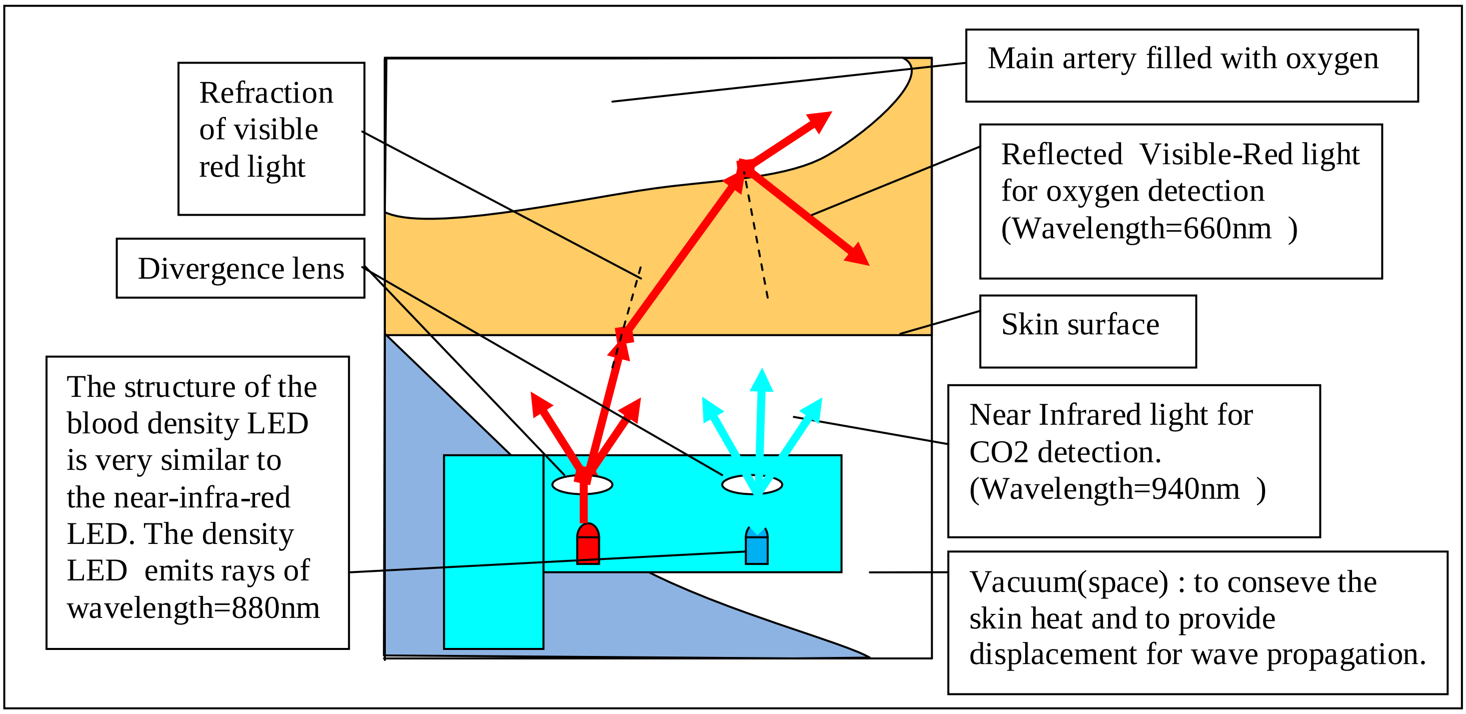


Fig. 5.5.3e Oxygen/CO_2 sensor (width = 3mm). [64]

The main artery of the wrist (radial artery) is filled with oxygen, as it had collected it from the lungs. The artery divides into capillaries giving away the oxygen loading to the body cells and receives new loads of CO_2. The capillaries recombine as veins filled with CO_2, and passes again through the wrist as the main vein of the wrist.

The oxygen and carbon dioxide ratio is determined by this sensor (Fig. 5.5.3e). The role of the lens is to diverge the rays in all directions to reach for the main vein and the main artery. The reflected ray will return back to the sensor with a certain thickness and intensity different from its starting point, for the ray has been hindered by the amount of oxygen in the vein. The same procedure applies for the carbon dioxide sensing near-infra-red rays, the returning rays will be partially consumed producing a thinner ray which will be detected by a photodiode. The photodiode should possess certain permeability **(**Fig 5.5.3f), since that it should be detecting different types and intensity of reflected, consumed, and returning rays (near IR with 2 different values for density and CO2, visible red light, thermal IR).

<u>Distributed Photodiodes:</u>

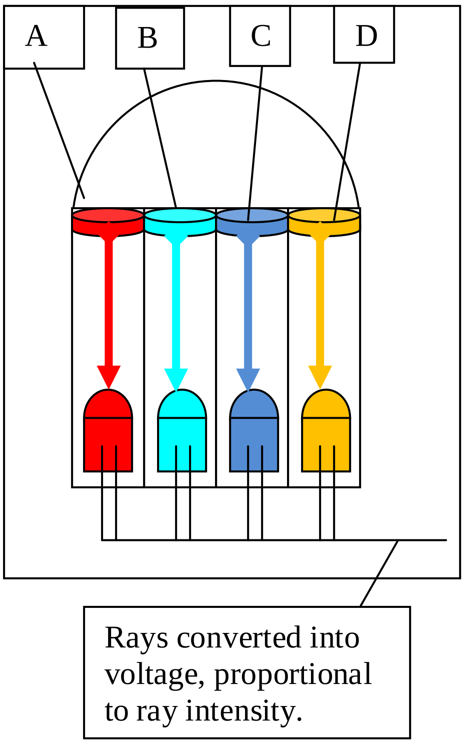


Fig.5.5.3f One photodiode containing 4 smaller selective photodiodes. [65], [66]

Next to each and every contact piezoelectric sensor there is a photodiode which converts infrared rays to voltage. The photodiodes are distributed along the sensor strip to increase the chances of them being hit by the reflected-back infrared rays, thus measurement is recorded. Four filters control the passage of the infrared rays inside the photodiode, according to wavelength value. This filtering technique (Fig.5.5.3f) has been used previously in optical devises and technologies. A: A filters that only allows visible-Red-infrared rays with a wavelength of 660nm. B: A filters that only allows near-infrared rays with a wavelength of 940 nm. C: A filters that only allows near-infrared rays with a wavelength of 880nm. D: A filters that only allows thermal-infrared rays with a wavelength of 100 micrometers. [67]

5.6 Improvements to Design Methodologies

5.6.1 A Systems Engineering Product Development Proposal: "Functional-Area-Implementation"

Stages Of The Proposed Method:

1) "Backward Synthesis of product Surface Area" Design Method.
2) Assigning proportional space on the product to the customer requirement value (D).

5.6.2 "Backward Synthesis of Product Surface Area" Design Method

This scheme will establish a pure reflection of the customer voice in a tangible product.

That is, building up and synthesising features that are compatible with requirement values, instead of rating features giving them certain values to describe how close they are from the customer voice. In order for a specific requirement to be accurately fulfilled, the proposed features (which satisfy this requirement) should have similar importance to the requirement importance.

We will now implement the customer voice proportions in the product requirements proportions to accomplish a backward synthesis technique.

Table. 5.6.2a Establishment of the “backward Synthesis” customer voice proportions.

Requirements	**Customer voice (%)**
1-Solutions for the “old age” problems	15
2- Multi-health-measuring design	14
3- accuracy of readings (automation)	14
4- easy to use (automation)	12
5- Design ingenuity	8
6- safety	8
7- comfort	6
8-reliability(automation)	5
9- moderate price	4
10-attraction	3
11-quick measuring	3

Table.5.6.2b Building the “Backward Synthesis” features.

Requirements	Backward Feature Synthesis “Square-area-oriented” Features.	Customer Voice
	The magnitude of the surface area that these added systems will occupy should be equal to the customer voice rating shown on the right hand side column for each and every requirement.	This should be the value of the customer voice and the % of area occupied by the added features on the left hand side column.
1-Solutions for the “old age” Problems	1) The processor embedded under the indicated surface covers the complete 30% area (along with the flash memory). The processor generates the overall automation of the product. Automation is the biggest solution for old people, and at the same time it makes the product extremely easy to use. The sub-surface area of the left circle indicated is fully occupied by a processor that makes life easy, and the same processor that provides a solution for the elderly people.	15
2- Design of Multi-health-device	1) The “blue belts” are made to be a surface area of interactions or a sensing platform between the sensors and the scalp-skin or the sensors and the wrist-skin. The whole surface area is brought to surround the head and surround the wrist.	14
3- Accuracy of	The EEG system supports the BP automation system	14

readings	and the general health status of the body, by detecting the BP-changing-factors and general health specific signals emitted by the brain.	
4- Easy to use	(same paragraph as requirement 1 ,above : repeated para.) Requirement 1 (15 points) + requirement 4 (12 points)=approx. 30 points=27	12
5- Design Ingenuity	MEMS microphones are selected to save space.	8
6- Safety	1) Alarms and warnings of the watch. 2) Emergency pull.	8
7- Comfort	Watch size control is situated under the screen surface; this is to add to the comfort of people wearing the watch.	6
8-Reliability :	1- The emergency system is a very reliable system that will be connected to several close relatives and friends of the patient. Whenever the alarm goes on after pulling the ring, when the patient is in trouble, the watch will automatically call a number of people informing them automatically that the patient is in danger.	5
9- Moderate Price	The sensor systems used in the bows are fairly inexpensive.	4
10-Attraction	The 3 small alarm lights are basically for alerting	3

	functions when accompanied by an alarm sound. Without the sound they show battery level and at the same time, they keep on flashing to satisfy this requirement and attract people.	
11-Quick Measuring	The embedded fast flash memory under the listening surface gives fast performance and occupies about 3 % of the sub-surface area of the auditory surface.(the flash memory is a miniaturised one)	3

5.6.3 Assigning Proportional Space on the Product to the "Importance Weight" (D)

We should be dividing the product into 11 sections, which is the number of requirements, and giving each section a proportional space area or cubic volume to the "Importance Weight" = (D).There are 11 values which should determine 11 surface areas.

This process will increase the acceptability of the people to products because they will not only know that their favourite features are included in the product, but they will also see it occupying nearly most of the product surface which can be a strong stimulus for purchasing. Having this concept in mind, the product designer can alter his components dimensions and characteristic, enlarging components with higher weights and decreasing the size of components that resemble the requirements with the lower weights. This type of method can only be applied after the function-oriented design is fulfilled. This method is about adding the feature and showing it as much as possible, if it is important; or hiding the feature appearances if it is unimportant, saving the space only for the important features.

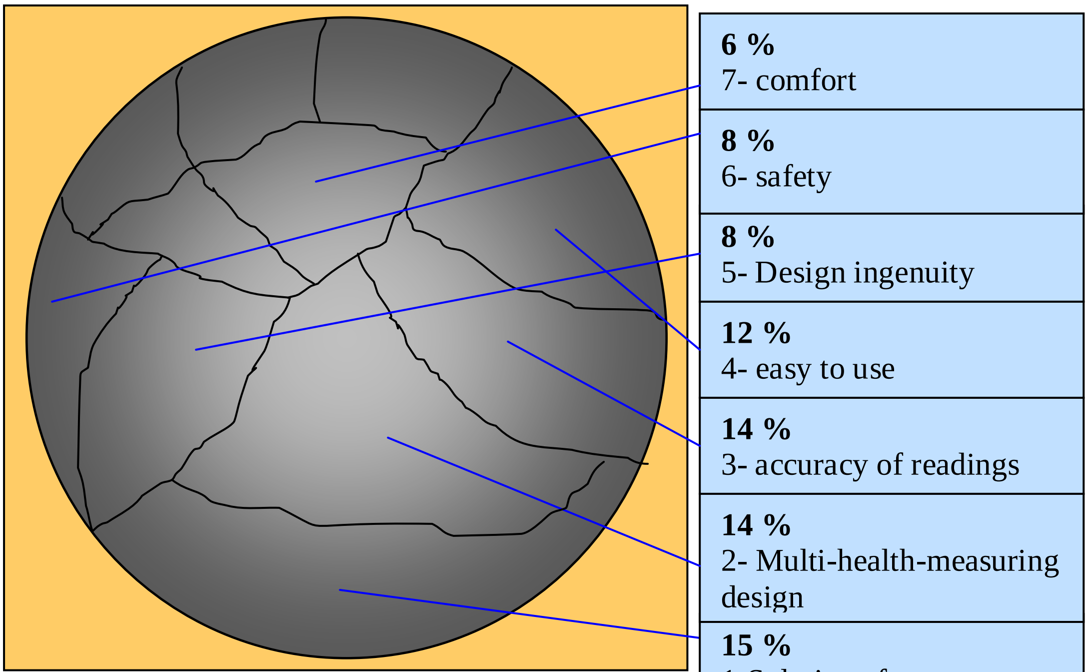


Fig.5.6.3a Example of Product Functional Area Method(Additive technique –Varying Segments).

Now we are going to apply the functional area division on the overall product.

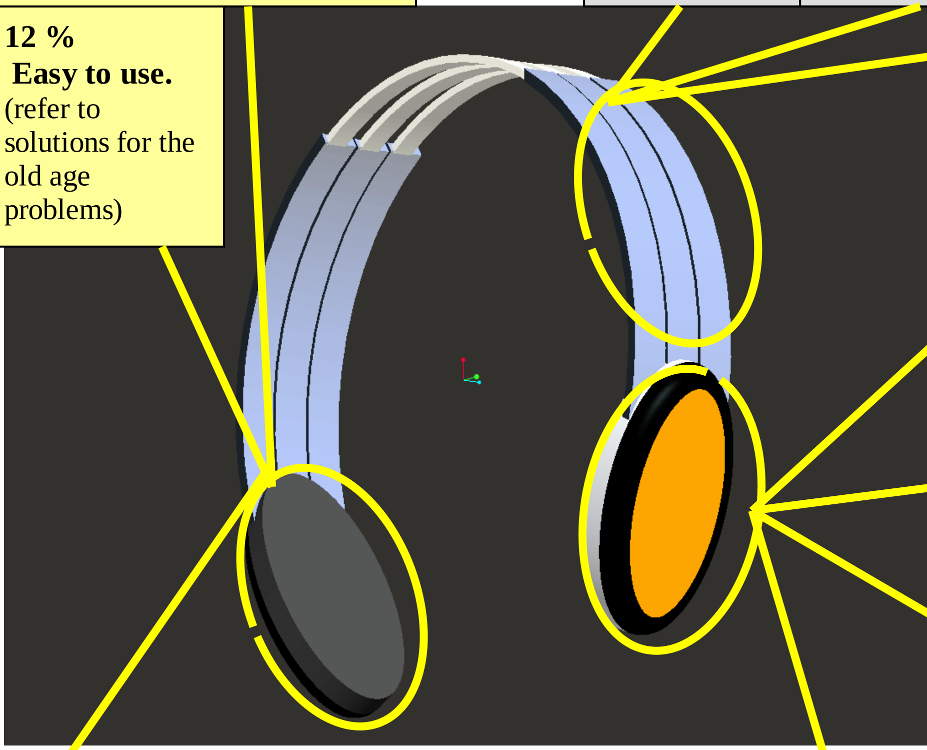
3 %
Quick measuring.
The embedded fast flash memory under the listening surface gives fast performance and occupies about 3 % of the sub-surface area of the auditory surface.(the flash memory is a miniaturised one).

14 %
Accuracy of readings.
(for surface area ,refer to Multi-health-measuring design.)

4 %
Moderate price.
MEMS sensors are used to fulfil the moderate price requirement (not expensive), and they occupy about 4% of the area since that they are extremely small.

14 %
Multi-health-measuring design.
This requirement , along with the **accuracy of readings** requirement , they both form 28 % of the indicated circle.

12 %
Easy to use.
(refer to solutions for the old age problems)



3 %
Attraction.
The 3 light diodes occupies exactly the same percentage of surface area as its customer voice ranking.(3%)

8 %
Design ingenuity.
The projector occupies about 8-10 % of the indicated surface area.

6 %
Comfort.
The adjusting system occupies a surface area proportional to its percentage. (6 % surface area)

15 %
Solutions for the “old age” problems.
The processor embedded under the indicated surface covers the complete 30% area (along with the flash memory). The processor generates the overall automation of the product. Automation is the biggest solution for the old, and at the same time it makes the product extremely easy to use. The sub-surface area of the left circle indicated is fully occupied by a processor that makes life easy, and the same processor that provides a solution for the elderly people.

5 %
Reliability.
A component which is high in safety and reliability at the same time especially for old people is the emergency pull system which has the most important function for old people.(5% area)

8 %
Safety.
The emergency pull system provides a life-saving safety button. The ring (to be pulled)covers almost 5% and the 3 small alarm lights covers 3% = total 8%.
The alarm lights warn the user that there is something wrong with his health.

Fig.5.6.3b Dividing the product into portions of variable amounts of feature concentration.

The 3 circles are equivalent to the Total surface area of the product.
3 circles = 90 %(Total values for customer voice = 92). 1 yellow circle = 30 %

92 % is approximately = 90 % surface area.

=> Top circle(14+14+4) + right circle(3+5+6+8+8)+left circle (15+12+3) = 90 % SA.

=> 32 % + 30 % + 30 % is approx. = 90 % SA.

=> 92 % is approximately = 90 % SA.

The goal has been accomplished, the distribution of the customer voice values are located on the surface area of the product proportionally (approximate proportionality).

5.6.4 "Harmonic Unity" of Sub-systems Cross-multiplications

Establishing Strong Relations between Components:

Rule 1 : The stronger the relation between any 2 components the more efficient is the system of the overall product.

Rule 2 : Any component's function should support the functions of each and every part or component in the entire product.

Recommendation : This scheme supports the QFD requirement No. 5, which is the ingenuity of the product.

This scheme follows a design theory which states the following:

"*Every component and subcomponent of a product should not contradict other components in function, and should strongly support each and every function of other components that co-exist in the same product. This enables the product to evolve as one unit, where if one part is faulty the other can be a substitute.*"*[4]*

Now we are going to cross multiply the partial systems of the product together , to make sure that their functions will not contradict each other, and that the subsystems supports each other.

If any 2 systems are found not to be supporting each other, new features will be proposed and implemented in the non-supporting system, so that it will become a supporting system (if possible) to each and every sub-system of the product.

Design alternatives should be generated by studying the relations between each and every pair of components which is the output of the multiplication process. The design alternatives should be generated if there is a close distance between the pair of components (part of the same major system – watch body). The pairs with far distance relations will be postponed till the end, since these are harder to make them support each other's functions.

In this study, only the relations between pairs of components are studied. Relations between 3, 4, and 5 components will be excluded because of the scarcity of time. These many-component-relations are possible and effective if there is no appearing relation between 2 components. In other words, these many-component-relations are established only when a single piece of component cannot handle or fulfil its function because of the nature of the overall product system that the component is part of. Therefore, many-component relationships are formed to fulfil one function only supported by 2 or 3 components at the same time in order to be fulfilled. Eg: The back support of the chair, the bottom support, and the legs all share the fulfilment of a single function which is the weight support of the user (3-component-relation). The back support surface and the bottom support surface unify to provide comfort to the user (2-component-relation).

A component with a certain function cannot have another component to support its function, only if 2 components unify together, the function of the first component can be supported.
Thus, the final goal of this design philosophy will be accomplished, which is to reach a “harmonic unity” of all the subsystems of the main system (the product).

Cross-Multiplications Between Components And Subsystems :

Table 5.6.4 Multiplication matrix.

	Body structure	Processor system	Automation sensor system	Speech system	Main upper part
Body structure	-	accepted	accepted	accepted	-
Processor system	-	-	-	-	rejected
Automation sensor system	-	-	-	accepted	-
Speech system	-	-	-	-	-
Main upper part	-	-	-	accepted	-

Accepted = accepted design solution

- = no design solution

Rejected = rejected design solution

The matrix produced 5 pairs of product sub-systems that can support each others’ functions (the support relation is not reversible, the first one will support the second, but the second will not support the first).

1) Body structure vs. Processor system :

Processor system function: Information manipulation and calculations.

Body structure function: To support the processor system function.

New Suggestion:

Should be providing connectivity and protection to the main processors; the material of the watch surrounding the processor should be a sort of insulator which will protect the processor from overheating. At the same time, the material should be robust so that the processor cannot be harmed by shocks. Also, the material of the product should have enough elasticity to allow the conversion from a watch to a headphone without breaking (Fig.5.3.2.2b).On the other hand; the body should provide connectivity passages for the wires to pass.

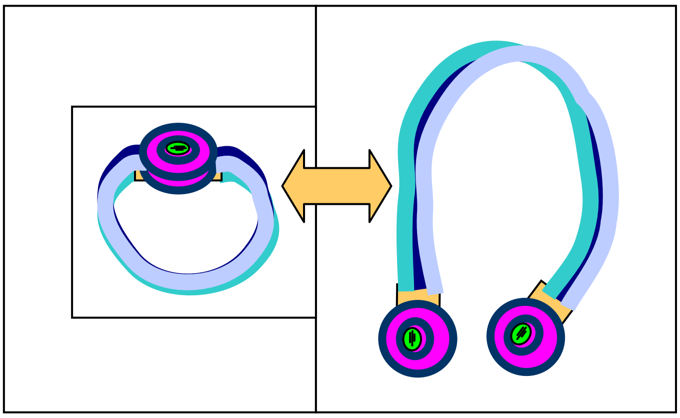


Fig. 5.6.4a Watch EEG conversion (accepted design solution).

2) Body structure vs. Automation sensor system

Automation sensor system function: Sensing.

Body structure function: Should also support sensor system function.

New suggestion 1: Body structure should be made of a material with a low density to allow easy penetration of waves, rays, and electric charges from wrist and scalp to watch body.

New suggestion 2: The electrodes have to press on the scalp by means of a curved structure leaning inwards to the circle.

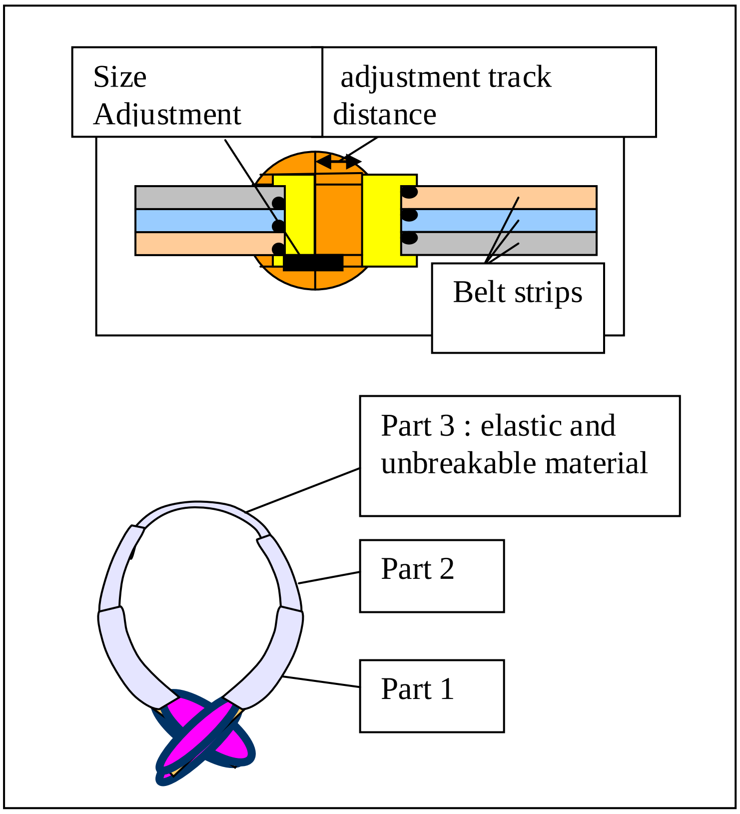


Fig. 5.6.4b watch-EEG conversion components (accepted design solution).

2.5) Body structure vs. Speech system

Speech system function : To enable communication between patient and watch.
Body structure function : Should also support Speech system function.

New suggestion : MEMS microphones to save space.

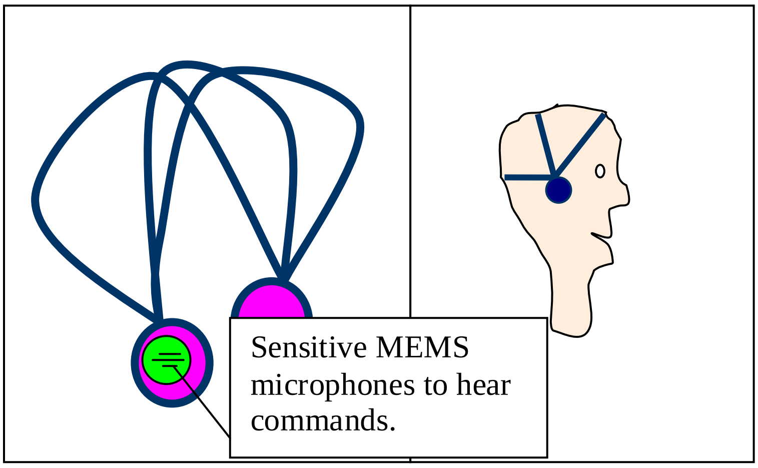


Fig. 5.6.4 c MEMS microphones. (accepted design solution).

3) Processer system vs. Main upper part

Processor system function: Information storage, manipulation, and calculations.

Main upper part : To support the processor system function.

New suggestion: The Development is an alternative storage facility if the watch storage area is getting large (thus this will produce a large and heavy watch). A Bluetooth device is added to be connected to computer large processers that can handle the analysis of acoustic/ultrasonic signals and send it back to the watch. The watch might also need a big storage capacity for many brain waves signals that shows numerous medical status of the body.

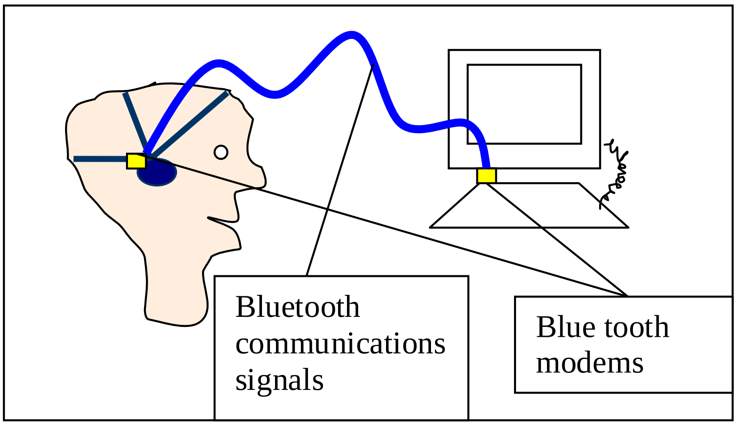


Fig. 5.6.4d Bluetooth communications. (rejected design solution).

4) Main upper part vs. Speech system

Speech system function: To enable communication between patient and watch.
Main upper part function: To support speech function.

New suggestion: A lighting and visual alarm to warn the patient that there is something important or dangerous to be said about his health and clinical information.

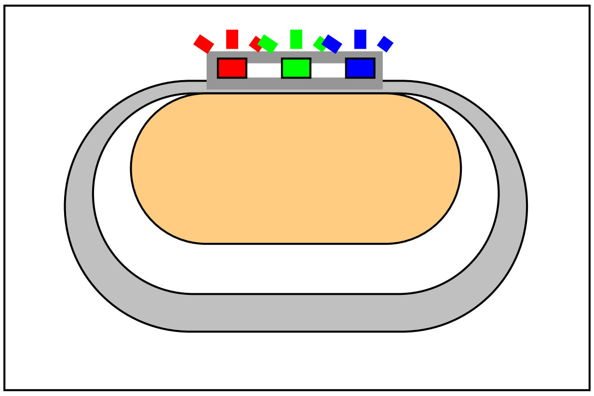


Fig. 5.6.4e Three-alarm-bulbs. (accepted design solution).

5) Automation sensor system vs. Speech system

Automation sensor system : Sensing.

Speech system function: To support automation sensor system.

New suggestion 1 : Developments Of An Emergency Pull System : The watch will have an emergency pulled string(emergency pull) fixed at the back of the watch main body. The user is to pull the string only when he is in fatal condition, and where there is nobody around to help him, or that he is not in a state which allows him even to call the emergency number or to his friends. The red string is linked to the wireless network where the emergency signal will be transferred to the ambulance to come.

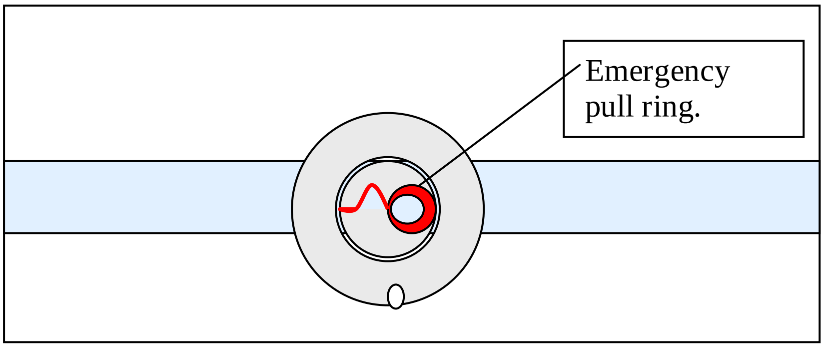


Fig. 5.6.4f Emergency system. (accepted design solution).

5.7 Summary

The first set of results in this chapter is the utilisation of the experiments' results in the product. Four methods were designed to detect the five factors. The methods are : a gyroscope sensor, an accelerometer sensor, a heart pulse sensor, and the digital information pattern. A combination of sensors are selected to automate the detection of each factor of the experiments. The detection of eating: movement of the hand in a steady manner(excluding drinking). The detection of hunger : the absence of those steady movements. The detection of sitting and standing: non-angular downward or upward movements of the body. The detection of the back angle : the digital information pattern will show proportionality between the back angle and the numerical BP values. The detection of sleepiness: Low pulse rate and rare sleeping movements.

The second set of results is the design and partial implementation of non-invasive techniques in the watch. Which means, proposing a non-invasive medical and portable “main sensory system” that will be responsible for executing most of the health measurements of the watch. The design comprises of different integrated MEMS sensors in a 2 cm “sensor strip” (built-in inside a ribbon) to be sticking on the skin surface of the “radial artery” and main vein of the wrist. The design is originated from the QFD evaluation and weighting schemes , which shows that the most compatible medical techniques with customer voice is the “noncontact infrared” and the “contact piezoelectric” techniques. The last section of this chapter (chapter 5) describes an added improvement to the QFD methodology where the “Importance Weight” values (part of QFD main matrix) generates proportional surface area values on the product. In other words, the most important requirement features should have components showing on the product, these components should occupy maximum surface area since that it has maximum importance. In addition, a popular design methodology is used in this study (harmonic unity of components) which supports the fifth requirement of the customer voice. This methodology dramatically enhances the ingenuity of the product, as it was demanded by the customer voice. The study yielded most of the design solutions of the product (e.g. EEG system). The study talks about 2, 3, and “many” component-relations which can increase the unity of product subsystems and generate alternative designs and alternative components as design solutions for the product.

Chapter 6 : The Proposal of A Partial Design of The “watch-headphone” Product

6.1 The Watch-Headphone Product and its Components

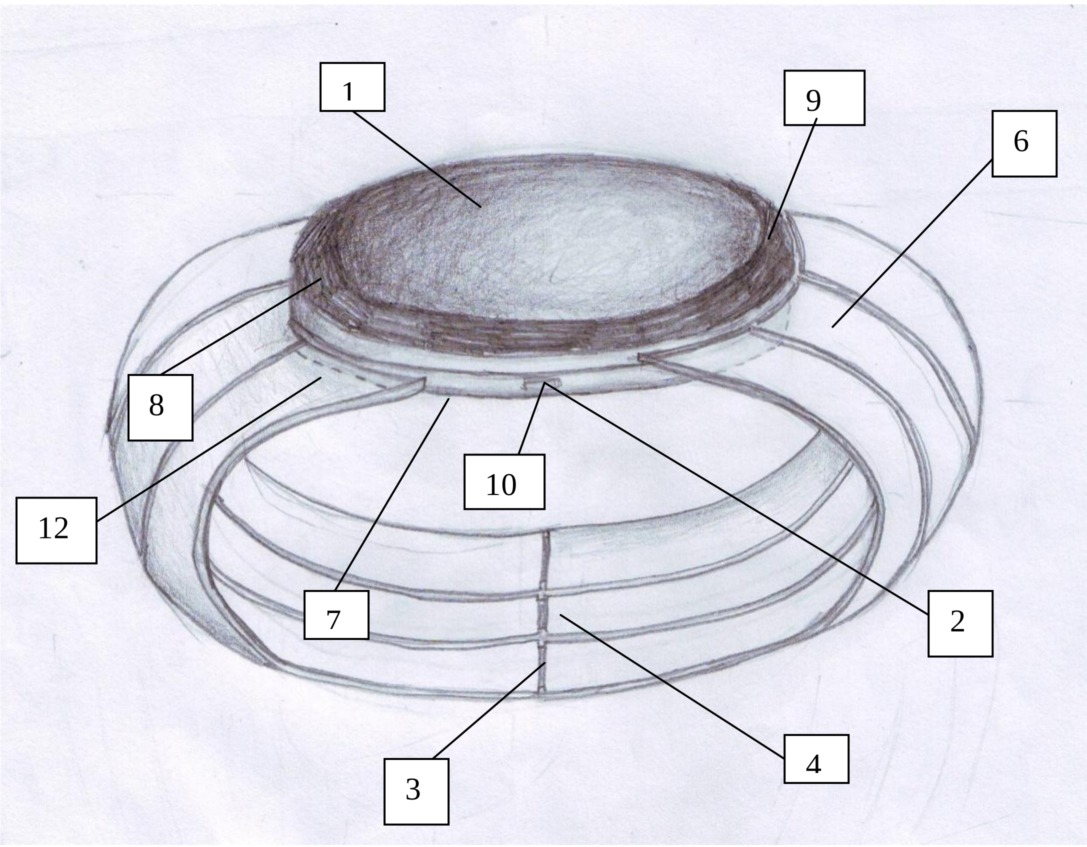


Fig. 6.1a Watch labelled diagram.

1-Display screen (Fig. 6.1 a, b, e)

2- Upper body ejector (Fig. 6.1 a, b, c, d)

3- Extension ejector (Fig. 6.1 a, b)

4-IR sensor (Fig. 6.1 a, b)

5-White belt (Fig. 6.1 b, c, d, e)

6- Blue belt (Fig. 6.1 a, b)

7-Lower half of upper part (Fig. 6.1 a, b, c)

8- Top half of upper part (Fig. 6.1 a, b, c)

9- 3-alarm-bulbs (Fig. 6.1 a, b)

10-Ejector socket (Fig. 6.1 a, b, c, d)

11- EEG Electrodes (Fig. 6.1 d, e)

12- Gyroscope and accelerometer (Fig. 6.1 a, b, e)

1-Display screen: The display screen will be situated in the top half of the upper body. All the medical information mentioned in this dissertation may appear on the screen as one way to present the information (the other way is to hear the information through the headphones).**2- Upper body ejector:** Enables splitting of the 2 halves (the top and the bottom one) when the user decides he want to use the product as headphones to listen to the watch's audio health information ; Or to scan his brain for diagnosis through the EEG system , which is also part of the product. **3- Extension ejector:** This brings out the white belt from inside the blue belt to convert the watch**.**
4-IR sensor: This sensor detects all the various medical issues described in this dissertation.

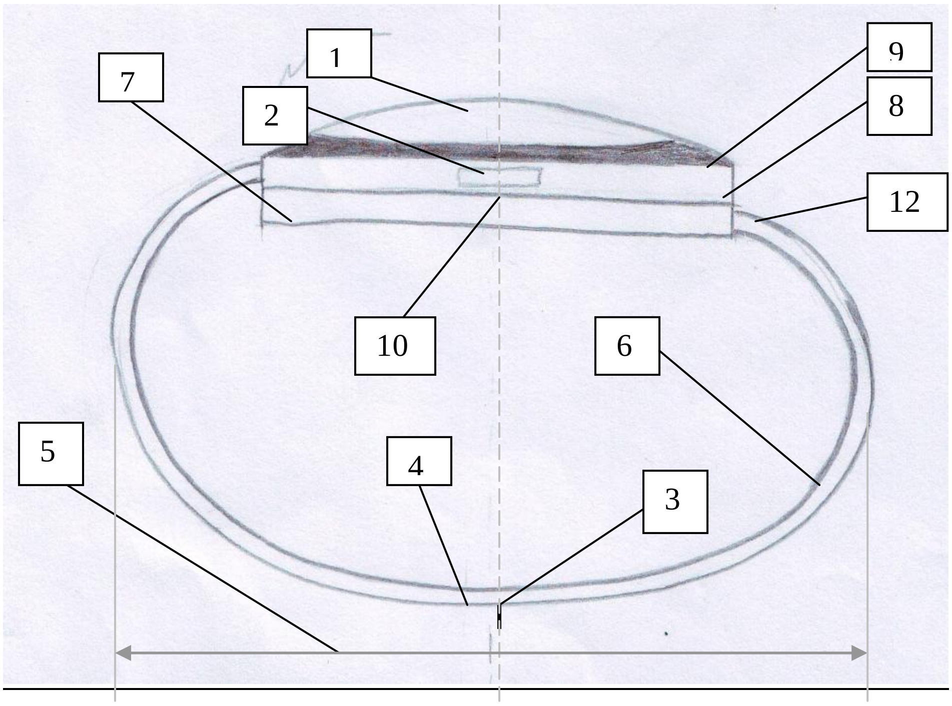


Fig. 6.1b Labelled Cross-section of the watch.

5-<u>White belt:</u> Fills the interior volume of the blue belt, the white belt appears only when the product is converted into headphones. It also contains EEG electrodes.

<u>6- Blue belt:</u> Is the watch's belt, which appears only when the watch is around the wrist. The watch belt contains the BP automation <u>sensors</u> and the <u>extension</u> <u>ejector</u>, and contains also <u>EEG electrodes</u>, <u>gyroscopes, and accelerometers.</u> **<u>7-Lower half of upper part</u>:** Is one of the 2 headphones placed on the users ears. It contains part of the processor and the <u>ejection socket</u> which bonds the 2 upper body halves together.
<u>8- Top half of upper part:</u> Contains the screen of the watch, and is actually one of the 2 headphones placed on the users ears. The top half also contains the <u>upper body ejector</u>, part of the processing system, and the <u>3-alarm-bulbs</u>.

<u>9- “3-alarm-bulbs”</u>: These bulbs will warn the user when one of his health measurements reaches a dangerous level (blood pressure).

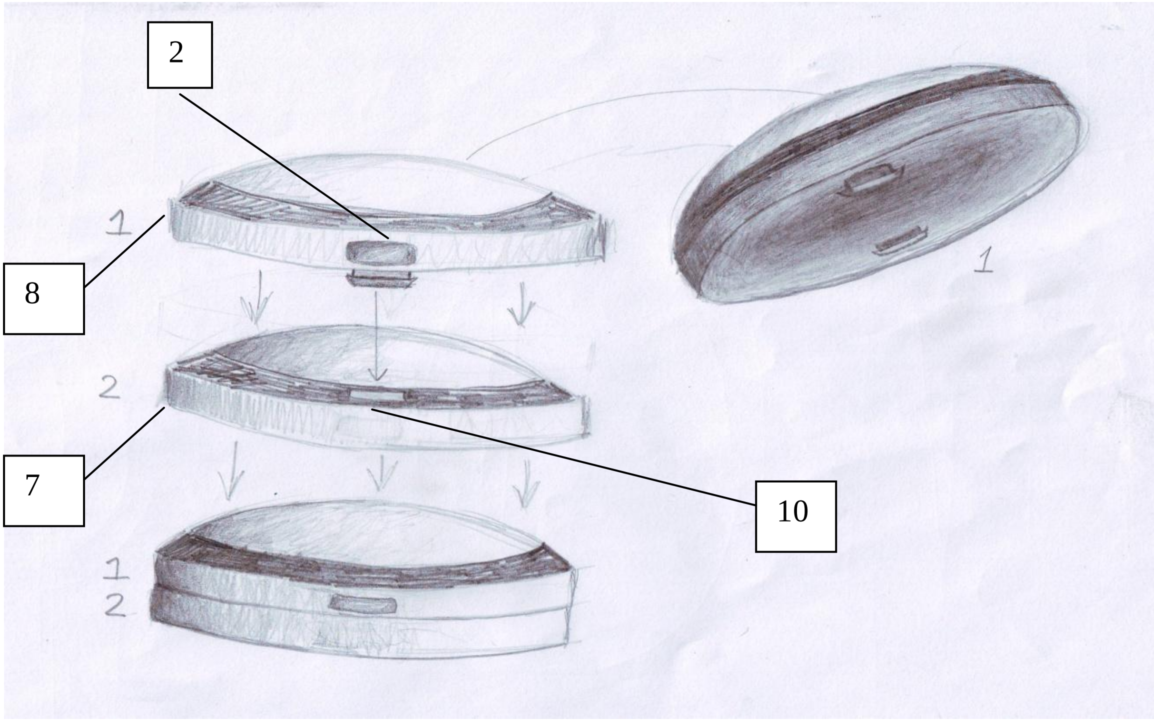


Fig. 6.1c Watch upper body release (2 halves).

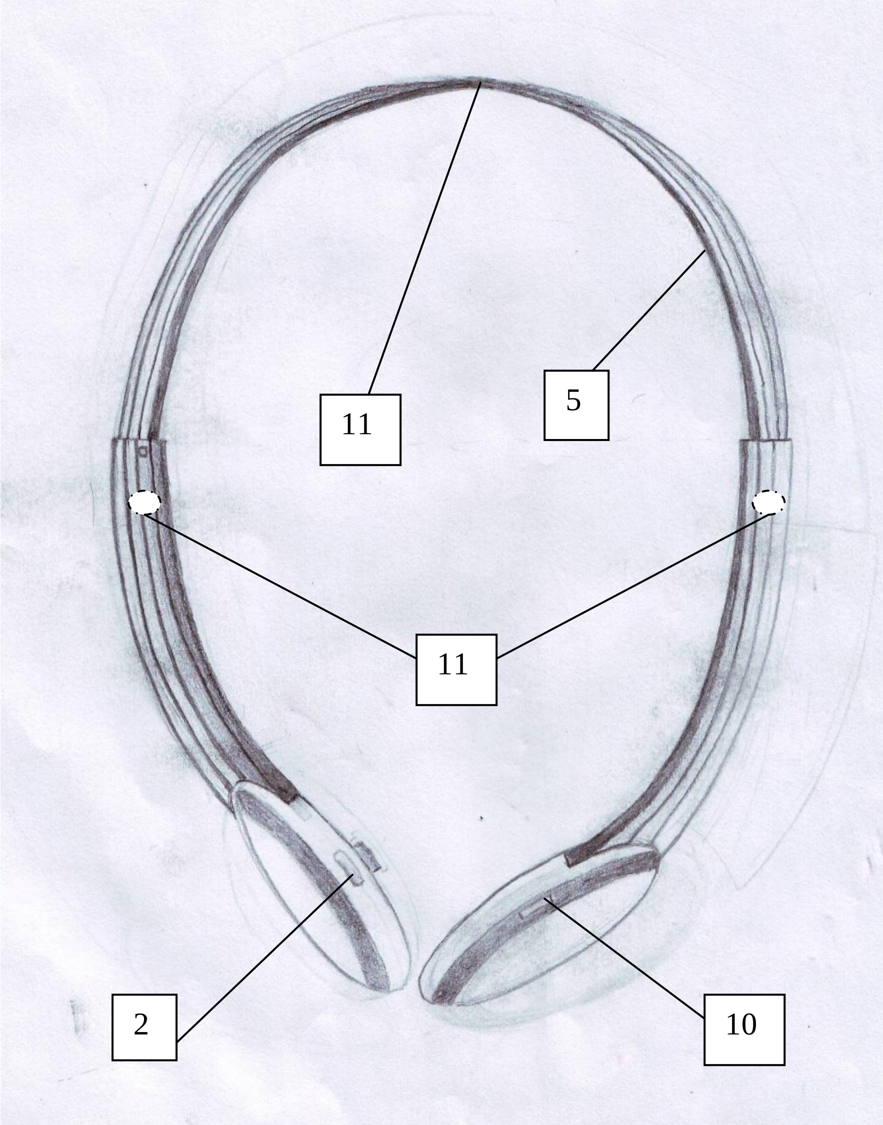


Fig. 6.1d Watch is converted into headphones.

10-Ejector socket: It is the socket of the upper body ejector which enables the top half of the upper body to grip to the lower one, creating a firm bond of the 2 halves of the upper body. **11- EEG Electrodes:** Are dry electrodes which receive the emitted brainwaves from under the skull and sends them to the processor for many-stage processing and comparison with already stored disease brainwave signals (these electrodes don’t need gel preparation of the scalp.

The gel makes the scalp and human hair more conductive in transmitting the brainwave signals). **12- <u>Gyroscope and accelerometer</u>:** Are part of the automation system of the BP readings experiments, mentioned in chapter 5.

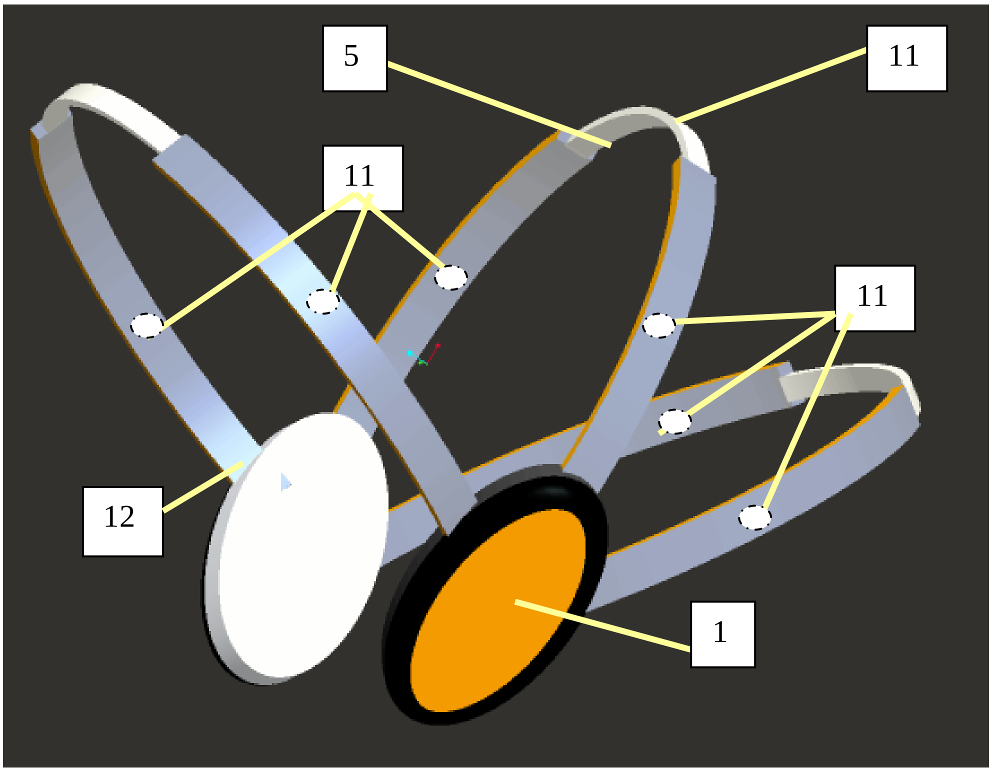


Fig. 6.1e Watch electrode-antennas are separated(proEngineer)

6.2 Watch Conversion Process

STEP 1:

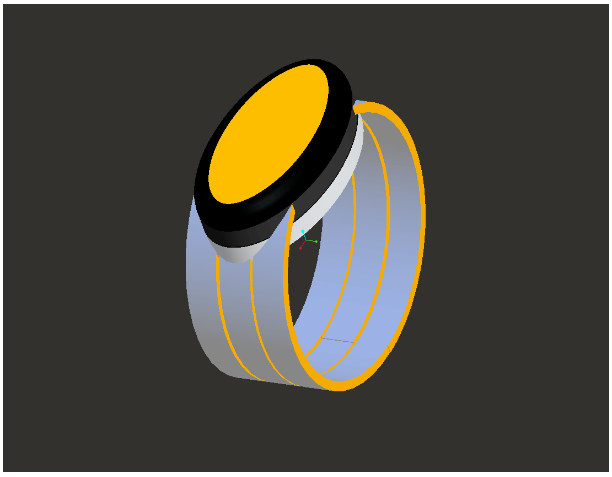


Fig. 6.2a Watch perspective view (ProEngineer).

As it was mentioned before in the “harmonic unity” design methodology, the material by which the bows (belt) of the watch should be made of a specific elasticity value. That is, the belt should tolerate continuous deformation by the user without breaking, when the watch should be converted into a headphone for brainwave scanning. The material should be chosen carefully so that the bow shape, which forms the headphones, will not go out of shape by constant stretching and usage. In fact, the bow shape of the headphones allows it to stick to the head without falling; this is why the rigidity factor of the material is important.

STEP 2:

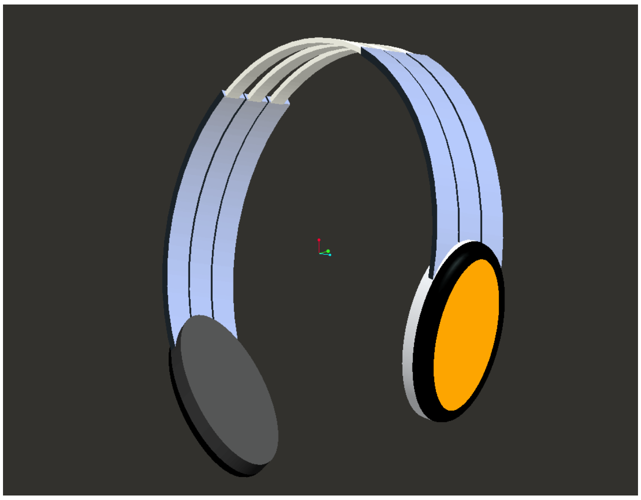


Fig. 6.2b Headphones perspective view (ProEngineer).

When the user is wearing the watch, the belt is supposed to be curled inwards creating a small ring-like diameter around the wrist. When the belt is released by splitting the upper part, the curl will open up, giving the instantly formed headphone a semi-circular shape which will not permit the user to wear it. This is why a mini belt (shown in the image –white colour) which occupies the inside volume of the original belt should be extended out of the original belt (blue colour in image) to complete the semicircular shape and give the headphone its usual shape. The white internal belt has the same length of the blue belt since it is fully contained inside it.

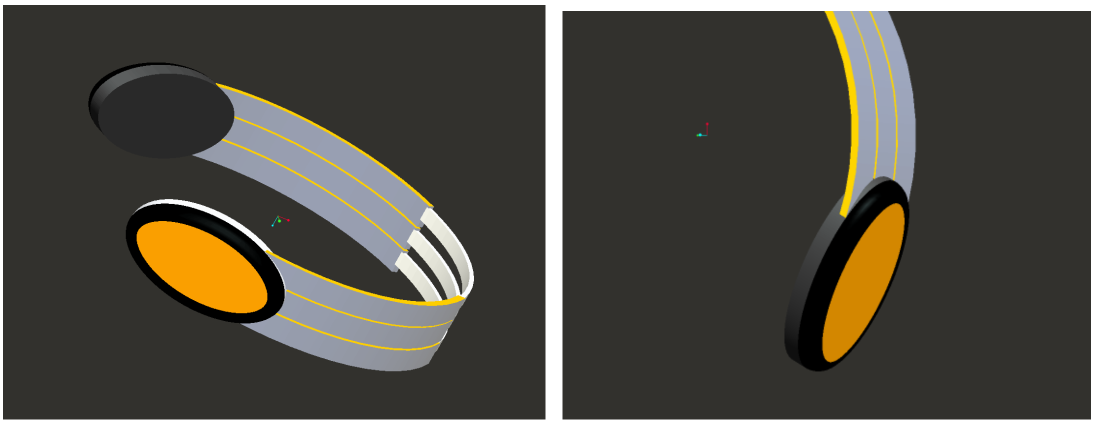


Fig. 6.2c Headphones images (ProEngineer Software).

This is the form of the watch after the upper body is split into 2 half's, and the white belt is extended out of the larger belt to cover the upper circumference of the scalp. The degree of curvature of the belts is shown in the above image. The more the white belt is extended the more the headphone is going to clip on the users head.

<u>STEP 3:</u>

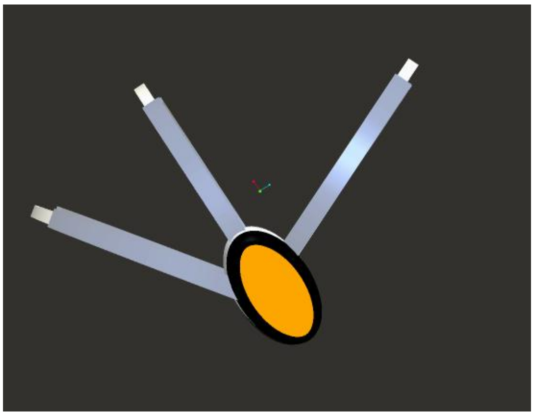


Fig. 6.2d Headphones side-view.

Separating the belt into 3 belts is proposed to allow the user to cover the full range of the scalp when needed. Separating the 3 belts of the headphones is not a must; this part of the design is an optional one. The reason for this feature is that some important parts of the brain (cerebellum , Frontal lobe , occipital lobe) are situated in the remote part of the skull (away from the centre **:** above the neck , above the forehead) , where it will be hard for the electrodes to receive clear brainwave signals.

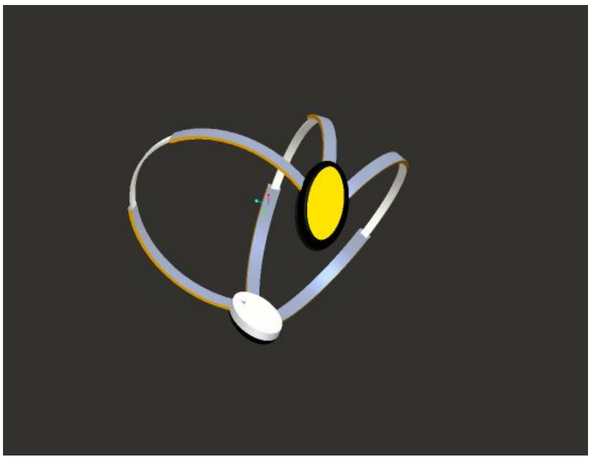


Fig. 6.2e Headphones bottom-view.

6.3 Market Selected or Software Designed Systems Components

6.3.1 A Design "To-Scale"

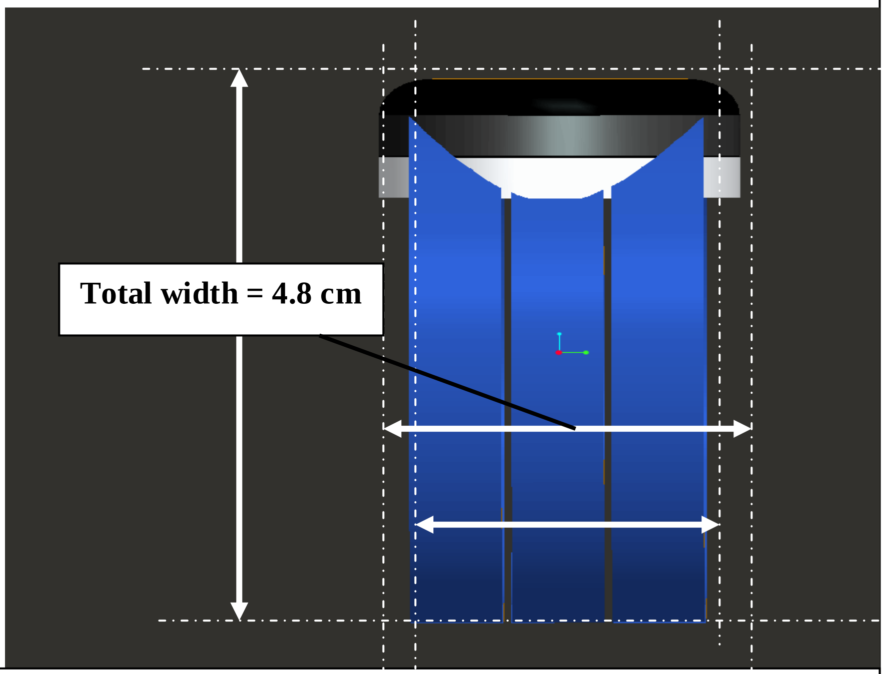


Fig. 6.3.1a Side-view of watch: The Design is to Scale:
(Height 7 cm x Belt width 4 cm).

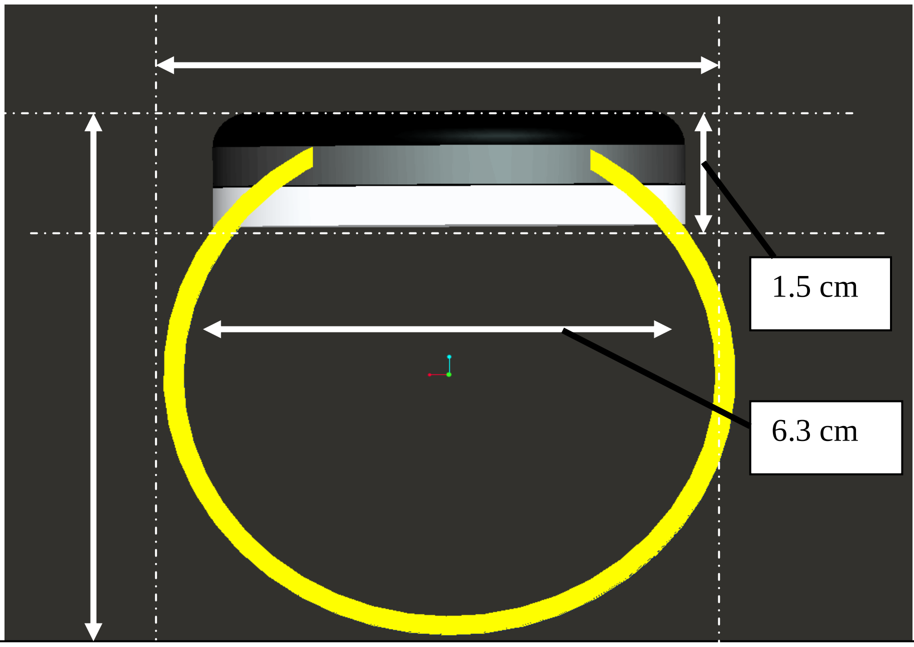


Fig. 6.3.1b Side-view of watch: The Design is to Scale:
(Height 7 cm x Width 7.5 cm)

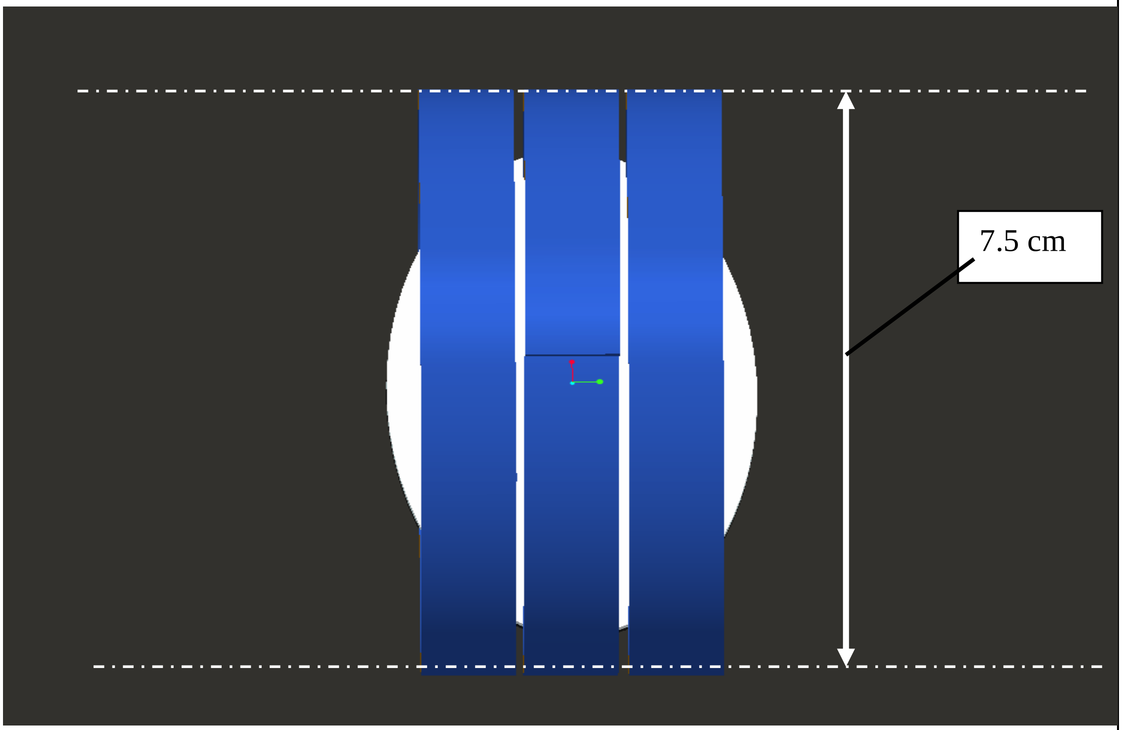


Fig. 6.3.1c Bottom-view of watch: (The Design is to Scale).

6.3.2 Blue and White Belts

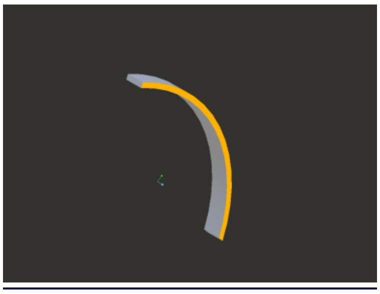
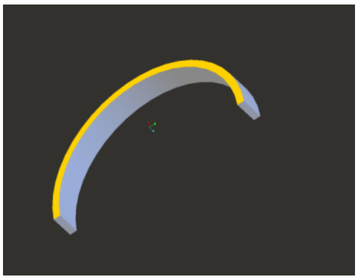
	

Fig. 6.3.2a Blue belt - Released headphone belt.	Fig. 6.3.2b Blue belt- Curled watch belt.	Fig. 6.3.2c White belt

6.3.3 Main Upper Part

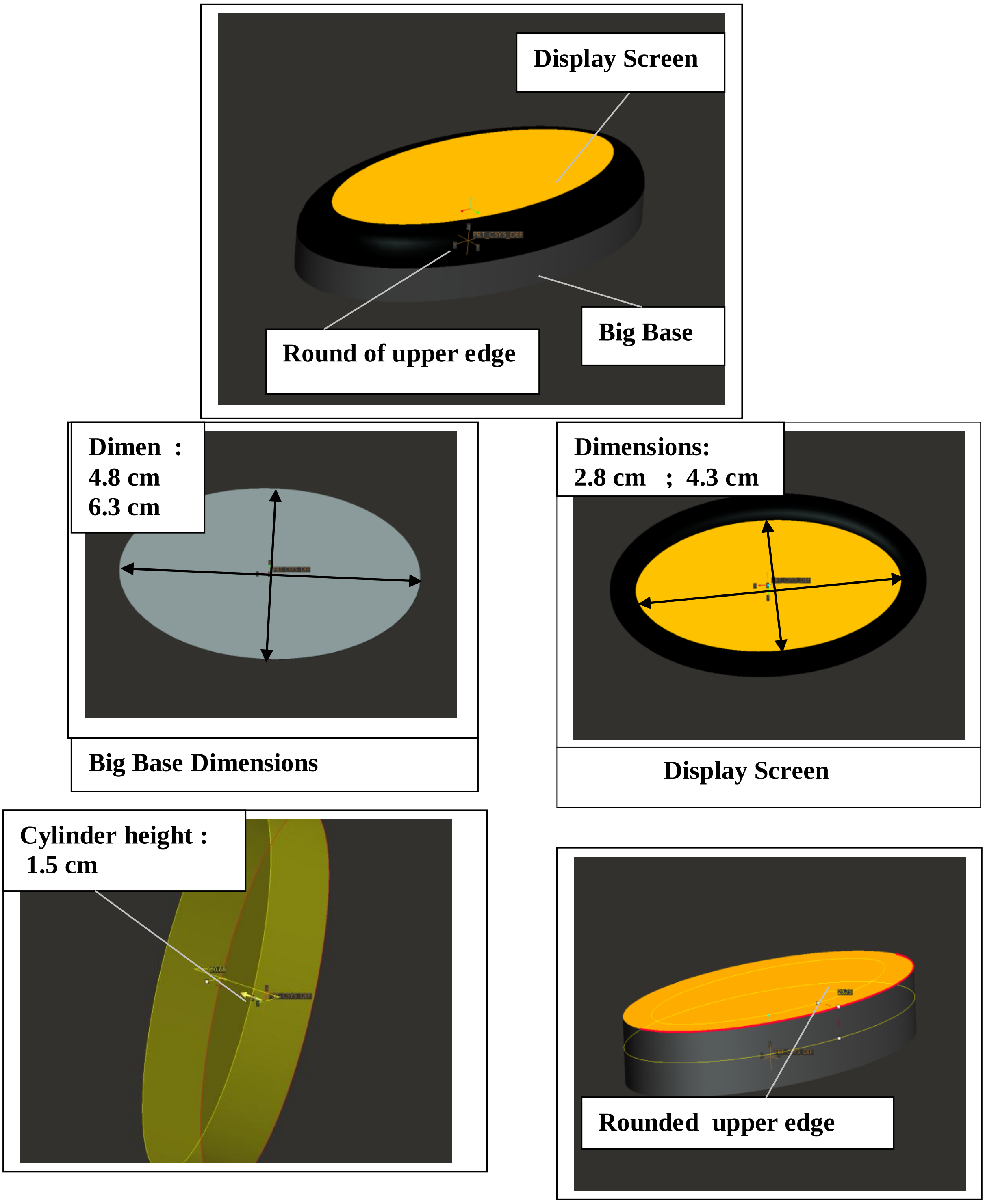


Fig. 6.3.3 Main upper part parametrs.

6.4 The Processor System

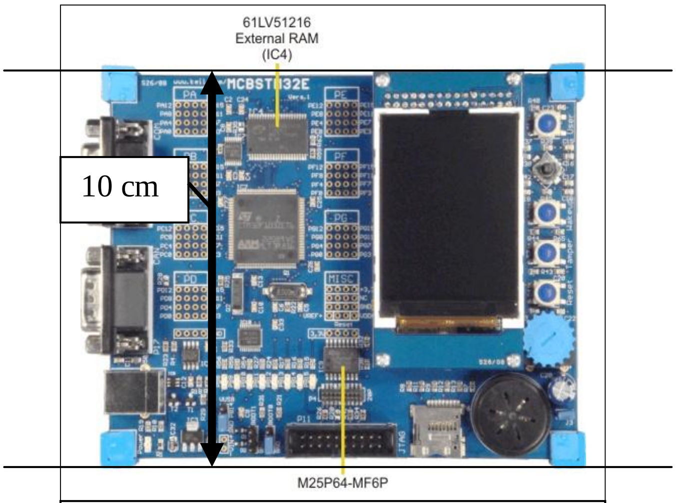


Fig. 6.4 Cortex-A8 - ARM embedded processor (10 cm x 10 cm), [27]

The cortex -A8 processor has a very flat surface area which can be altered to fit into the non-flat volume of the watch ; also the various components of the cortex-8 can be further managed, compacted, and miniaturised to save maximum amount of space.. This can easily be done by altering the dimensions of the cortex-8 into a 5cm x5cm x 2 cm volumes in the first headphone and another 5cm x5cm x 2 cm volumes in the second headphone. Thus the processor will be distributed in 2 sides, and connected by an essential wiring which will fill the inside volume of the white belt and the blue belt. The wiring can also be extended with the extension of the white belt to fit the head of the user.

Some of the chips, like the Cortex processor will be substituted with other more advanced chip technologies that will be selected below:

Cortex, if combined with ARM Neon technology can support the EEG device since that it is a processor that is specialised in signal processing. In addition to signal processing ARM neon technology is a natural multimedia dedicated processors giving all the sharp images, video encoding /decoding, image processing, telephony, sound clarity and synthesis. [38]

6.5 Phase -Change Memory Technology and Other Miniaturised Memory Storage [68]

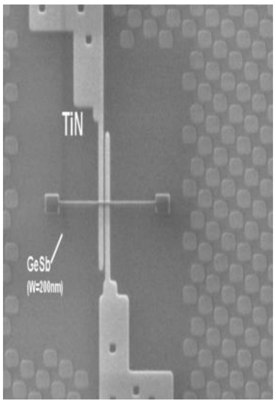


Fig. 6.5a Phase Change Memory Technology (500nm x 500nm): [69]

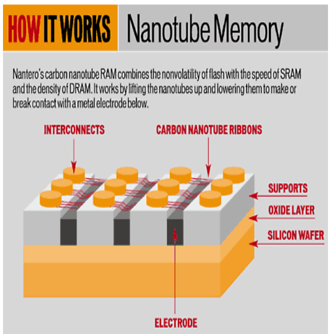


Fig. 6.5b "Nantero Inc." Product: Nano-tube-memory. [70]

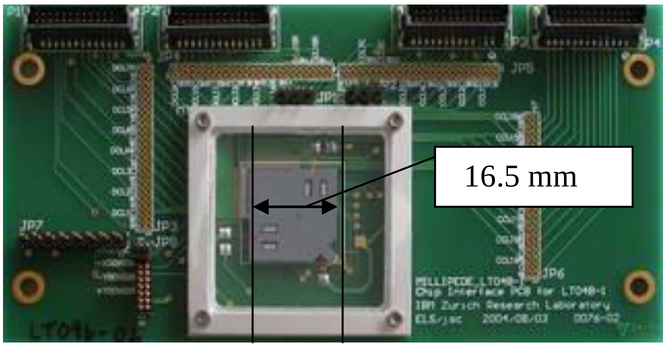


Fig. 6.5c An IBM developed Millipede storage device. (16.5 mm × 17.5 mm × 1.2mm) [71]

The Phase Change Memory Technology (2008) is developed by IBM, Macronix, and Qimonda. It is a faster, less space consuming, and needs a lot less energy than the flash memory. The Millipede storage device contains **1 Terabyte** (=1000 Gigabytes), this device is very suitable for advanced watch technology since that it saves a lot of space.

6.6 MEMS EEG Electrodes

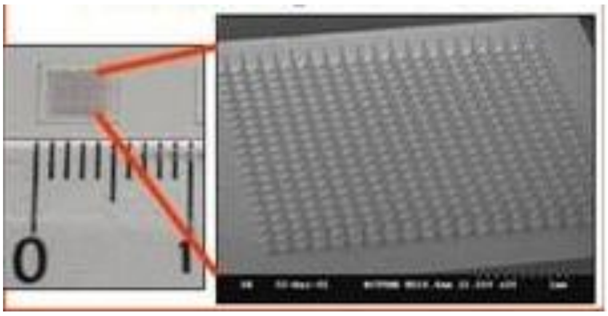


Fig. 6.6 MEMS Dry electrode (5mm). [72]

These electrodes will save a lot of space because they have mm dimension range, unlike other usual electrodes which are much larger in size. The electrodes are wireless sending physiological signals to the watch processor without the use of wiring. These miniaturised electrodes has the ability to ignore or eliminate extraneous body movements and signals and detect only the desired scope of signals (physiological signals).

6.7 Discussion

Let’s assume that an old woman wants to use this portable non-invasive medical device. The old woman decided to go and visit her friend in the neighbourhood.
As the woman was walking, the watch gave an alarm sound. The woman gave a close look at the watch screen to read the message but she couldn’t because of her bad eyesight. The woman decided to convert the watch into headphones so that she can listen to the message instead of reading it. The woman had put on the headphones and pressed a button on the “top half of the upper part” to activate the message. The following message was displayed “ *BLOOD PRESSURE = 70 / 40 – BELOW NORMAL* ”. The woman’s blood pressure has dropped below the normal level which means that something is wrong with her or with the health.
In 30 minutes another alarm went on, but this time with a louder and different sound, similar to the ambulance alarm. This time the message has given a hazardous value:

“ *BLOOD PRESSURE = 30 / 10 – LIFE IN DANGER* ”, which implies that the woman’s life is in danger. In this case the device will automatically execute the emergency button (without pulling a string) which is connected to a medical and emergency helpline (literature review-chapter 2). Usually, the emergency button is a red string with a red ring to be pulled by the user manually if her life is in danger. If any of the measured parameters will reach a life threatening level, the watch will automatically call the ambulance.

In another occasion, the old woman was laying in bed since that she was not feeling well in that day. Meanwhile, the watch was detecting body temperatures (through the infrared thermometer) that are above the normal value. The watch will consider that the rise in the body temperature of the old woman can be due to illness and will decide to check for illnesses using the built-in EEG system as a “ just in case ” action , where if no illness is detected a special message will be displayed. The watch will display this message on the watch screen: “ *CONVERT TO EEG* ”, anyway the user has to convert the product into headphones if she cannot see the message properly, where she will again listen to the message through the headphones audio voice. The old woman had separated the “belts” of the headphone so that the whole scalp area is covered by the electrodes inside the belts. After a couple of seconds the old woman could hear this message “ *AT LEAST BODY FATIGUE = (HIGH) ; TEMP* = 38.5 C ; *CURE = 7-12 HOURS OF SLEEP ; CHECK DOCTOR* ” which means that the device has detected a body fatigue signal of a high magnitude that usually appears as a result of exhaustion in that particular day. The watch determines the cure for such a problem which is many hours of rest, and warns the user that the reason for the high temperature could be partially caused by another health problem which means that the old woman should see the doctor. The old woman went to sleep for 2 hours when she was awakened by an increasingly loud alarm from the watch. The watch processor is considering that the body temperature should drop after the 2 hours of sleep; instead the new automated temperature measurements show a value of 39.5 after 2 hours of sleep. The old woman wakes to listen to the watch message: “ *TEMP* = 39.5 C; *CALL DOCTOR (URGENT); PRESS MESSAGE ON/OFF BUTTON WHEN DOCTOR ARRIVES* ”.

The woman did call the doctor and she was given the necessary treatment but she had forgotten to press the button as the watch had advised. Soon after the doctor has arrived the ambulance has arrived too. The watch had automatically called the ambulance since that the users’ body temperature is very close to the hazardous levels, and the woman did not press the cancellation button when the doctor has arrived. This was a safety procedure made by the watch. The watch had started a stopwatch time of one hour since its last warning of the urgent presence of the doctor was displayed. At the end of this hour the emergency was scheduled to be summoned automatically, should the woman press the cancelation button during this hour, the emergency call will no longer apply

6.8 Summary

Chapter 6 shows the possibility of fitting an embedded type processor in a wrist-warn-watch which has a slightly larger size than normal watches.

Most of the components of the watch body are designed, the conversion process is explained, and various dimensions of components are determined. MEMS and NEMS memory units are selected as alternatives to larger components, in order to achieve miniaturisation which is a basic aim of the study.

Chapter 7 : Conclusions & Future work.

7.1 Recommendations & Conclusions

The conversion process of the product from a watch to an EEG system has made it possible for the laboratory EEG system, or the videogame EEG to be as portable as a mobile phone.

The further development of this product will increase its automation functions, making life easy for the users. The users will not be obliged to visit the doctor as frequently as in the past. They will be able to know what is wrong with them, as the watch will be doing constant non-stopping checks on their health. It will also be easier for the doctors, to extract accurate information from such devices about the patients health parameters history (for how long have certain cell stayed in the blood) , which will lead to more accurate diagnosis by the doctor especially if the patient is suffering from dangerous and "hard to diagnose" diseases.
Through further developments, the watch could also have the ability to suspect the presence of a certain disease in its user body [73], and to take the necessary actions to confirm if the user is really infected referring back to its large memory which contains a database of disease symptoms. The watch might if necessary photograph body images through infrared rays. But this can only happen if the cm-range infrared cameras are miniaturised to at least a mm-range.

The review of this thesis has reached results, which indicates, that there is a fare possibility for ultrasonic (ULT.SO) sensor technology to fully inspect the blood stream through the wrist artery. The ultrasonic inspection (if proven to work) can measure and identify the amount and type of germs in the blood, nutrition in the blood, hormones in the blood, blood cells, cancerous cells, and other medical relevant substances or particles. In other words, ULT.SO is a very promising blood inspection method for portable medical devices.

At this stage , our product can only warn its user if 3 of the "health vital signs" reach a hazardous level : The heart pulse rate , the body temperature , the blood pressure BP. There is a possibility that the fourth vital sign measurement can be added to our product, if an ULT.SO sensor is to be added. The fourth vital sign is the respiratory rate of the human lungs which is in a remote distance from the wrist area.

Solutions have to be proposed to cut down the expenses of this product. It is highly recommended to create a business strategy which will cut down the expenses of the medical product.

The medical watch can be used for a usage different from the one it was designed for in the first place (medical measurement). Now, after the evolution of the product through various QFD evaluations, analysis, and stages, it appears that a more efficient and profitable method of building it is applicable. It should be built for all segments of the society (including children, and not necessarily the elderly segment only.)
The only system that the watch needs to become a product used for all ages is the entertainment multimedia system(has TV , MP3, computer-brainwave mouse , mobile phone) .

7.2 Future work : Description of the More Developed Product

(Refer to Appendix A for more details)

The more developed product is made out of a watch and head-top (head - mounted computer system) convertible system. (The portable computer can become a watch and vice versa).It is comprising of 4 sub-products: A Head-top (head-mounted computer), A Non-invasive medical system, A mini-projector system, An EEG/BCI device
…………..all worn on the head and included at the same time.

Four products in one	Financial cost
The Head-top	expensive
The Non-invasive medical system	moderate
Automated advertisements on TV (harnessed by the product).	business
BCI Brain-computer-Interface	moderate

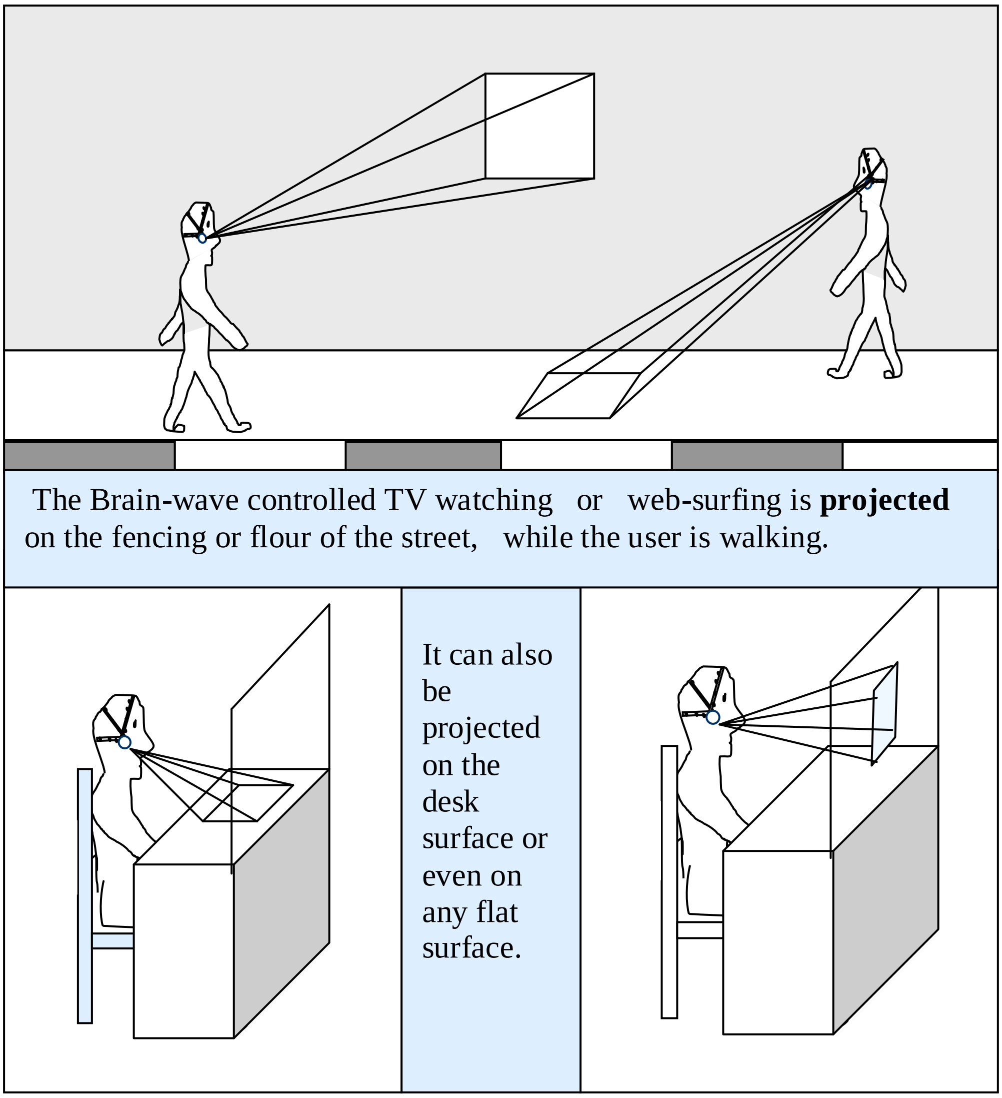


Fig . 7.2b Human -computer interface (HCI) while walking. [74]

There are only 2 improvements, which if added to the initial medical product will form a “portable computer” instead of a portable medical device. The 2 improvements are the addition of a MEMS projector to display the screen on surfaces , and the installation of embedded systems software(miniaturised processor) , BCI software(mouse substitute), and other software that we use in everyday life on our laptops and office computers(Ms word, digital TV).The function of the projector is to allow a “portable-usage” of the computer even while walking, the same way mobile phones allow portable talking with friends (10 years ago stationery phones where more common than mobile phones).

As it is shown in Fig 7.2b the user can surf on the internet while walking by an automated projection of the screen on building walls and street fencing.

The design database will pick designs as a substitute for bad designs by referring to design types that took high ratings in the past. The program will learn which designs to show (close to the previously selected ones). It will always keep in its memory deigns with the highest ratings and it will remember the features of these designs,……… like colour, shape, material type, volume geometries, or concept meaning..etc. This is because if a sub-part is going to have a low rating, the computer will substitute its design with one with features inspired by high rating designs, so that the substitute design too will have a high rating.

References

[1] Ellen Meara and Chapin White, (2004), Trends in medical spending by age, **HEALTH A F FA I R S[online],** VOL.2 3 , NO 4 , pp179-181
http://content.healthaffairs.org/cgi/reprint/23/4/176.pdf

[2] Monica Botero, MD, David Kirby, Emilio B. Lobato, Edward D. Staples, MD, and Nikolaus Gravenstein , (2004) , Measurement of Cardiac Output Before and After Cardiopulmonary Bypass:Comparison Among Aortic Transit-Time Ultrasound, **Journal of Cardiothoracic and Vascular Anesthesia**, Vol 18 , No 5 , pp 563-572.

[3] Ronald L. Broadwater, (1982), Blood pressure and heart rate measuring watch , **Free Patents Online[Online], Patent No. 4331154, pp.1-3.**
http://www.freepatentsonline.com/4331154.pdf

[4] U-Xuan Tan, (2008) , Estimating Displacement of Periodic Motion With Inertial Sensors , **IEEE SENSORS JOURNAL**, VOL. 8, NO. 8.

[5] Greg Freiherr, 11/5/2008, Micromachines Making Headway in Medical Applications**, Medical Device & Diagnostic Industry [Online]**, p.1.
http://www.devicelink.com/mddi /archive/97/08/013.html

[6] Robert S. Seeley , 23/5/2008 , The Future of Medical Microelectromechanical Systems, **Medical Electronics Manufacturing [Online]**, p.1.
http://www.devicelink.com/mem/archive /96/01/003.html

[7] Wei Tech Ang, (2007) , Nonlinear Regression Model of a Low-g MEMS Accelerometer, **IEEE SENSORS JOURNAL**, VOL. 7, NO. 1, pp81-87.

[8] R. Stadler , M. Forshaw, (2002), The performance of hybrid-molecular architectures with current CMOS technology as a reference, **Elsevier**, pp930-933.

[9] Kanakasababapathi Subramanian, Jeffrey B. Fortin, and Kuna Kishore, (2006), Scalable Vertical Diaphragm Pressure Sensors:Device and Process Design, Design for Packaging, **IEEE SENSORS JOURNAL**, VOL. 6, NO. 3, pp618-622.

[10] Michiko Seyama, Iwao Sugimoto, and Tomoko Miyagi, (2002), Application of an Array Sensor Based onPlasma-Deposited Organic Film Coated Quartz Crystal Resonators to Monitoring Indoor Volatile Compounds , **IEEE SENSORS JOURNAL**, VOL. 2, NO. 5, pp422-427.

[11] Morgan Electro Ceramics, 16/4/2008, Ultrasonic Blood Pressure Sensors, **Morgan Electro Ceramics**, pp.1.
http://www.transducer-sensor.com/sensors_bloodpressure.html**.**

[12] Jingkuang Chen, Xiaoyang Cheng, Chien-Chang Chen, Pai-Chi Li, Jian-Hung Liu, (2008), A Capacitive Micro machined Ultrasonic Transducer Array for

Minimally Invasive Medical Diagnosis, **JOURNAL OF MICROELECTRO - MECHANICAL SYSTEMS**, VOL. 17, NO. 3, pp600-609.

[13] PCB piezotronics, (2008), PCB Sensor Technologies and instrumentation, **Direct Industries**, VOL 1, p 29. http://pdf.directindustry.com/pdf/pcb-piezotronics/pcb-sensor-technologies-instrumentation-7413-20287.html#pdf_20287

[14] MISTRAS Group, 10/3/2008, Unidirectional Sensors, **Physical Acoustics Corporation[online]** , p1. http://www.pacndt.com/index.aspx?go=products&focus=/ sensors/unidirection.htm.

[15] MISTRAS Group, 2/7/2008, Differential Acoustic Emission Sensors , **Physical Acoustics Corporation[online]**, p1.

[16] MISTRAS Group, 30/7/2008, Miniature Sensors, **Physical Acoustics Corporation[online]**, p1.

[17] Jingkuang Chen, Xiaoyang Cheng, I-Ming Shen, Jian-Hung Liu, Pai-Chi Li, (2007), A Monolithic Three-Dimensional Ultrasonic Transducer Array for Medical Imaging, **JOURNAL OF MICROELECTROMECHANICAL SYSTEMS**, VOL. 16, NO. 5, pp1015-1023.

[18] Stephen A . Austin, (1997), Device and method for locating flow blockage in a three-dimensional object, **Free Patents Online[Online]**, Patent No. 5617869, pp.1-5.Freepatentsonline.com /5617869.html

[19] Thomas Liljenberg, (2004), Active Acoustic Spectroscopy**, Free Patents Online[Online]**, Patent No. 0006409 A1, pp.1-8. http://www.freepatentsonline.com/20040006409.pdf

[20] Stephen A . Austin, (1997), Device and method for locating flow blockage in a three-dimensional object, **Free Patents Online[Online]**, Patent No. 5617869, pp.1-5.freepatentsonline.com /5617869.html

[21] Wikipedia, 3/5/2008**,** Infrared thermometer, **Wikipedia Online Encyclopaedia**, p 1. http://en.wikipedia.org/wiki/Infrared_thermometer .

[22] Ming-Chun Hsieh, (2002), Design and Fabrication of a Novel Crystal SiGeC Far-Infrared Sensor With Wavelength 8–14 Micrometer, **IEEE SENSORS JOURNAL**, VOL. 2, NO. 4, pp360-364.

[23] Georgi et al, (1989), Blood flow Detection device-electromagnetic blood pressure measurement, **Free Patents Online [Online]**, Patent No. 4881413, All pages. http://www.freepatentsonline.com/4881413

[24] Glucowatch Ltd, 1/6/2007, A portable Medical watch that can measure Blood Sugar, **Cygnus Inc**, p 1. http://www.glucowatch.com/..............page under construction
[26] University Of Maryland Medical Center, 7/6/2008, Patients With Diabetes Can Test New Glucose Monitoring Device That Just Might Make Finger Prick Test Obsolete, **ScienceDaily**, p 1.
http://www.sciencedaily.com /releases/2001/07/010724081534.htm

[27] American City Business Journals, 15/6/2007, Area practice will test diabetes monitoring system**, Kansas City Business Journal**, p1.

[28] FitSense, 22/3/2008, medical watch, **FitSense Technology**, p1.
http://train.fitsense.com/default.asp

[29] Haifeng Chen, Donghee Ye, Jungtae Lee, (2007), Development of a Portable EEG Monitoring System based on WLAN, **IEEE SENSORS JOURNAL - IEEE International Conference on MonE02 Networking, Sensing and Control**, pp460-464

[30] Victor H. Fischer, (1965), Detecting physiological conditions by measuring bioelectric output frequency(Diabetes : sugar level) (carbon dioxide level), **Free Patents Online [Online]**, Patent No. 3195533, pp.1-5.
http://www.freepatent sonline.com/3195533.pdf

[31] J.R. Ives, N.R. Mainwaring, K.B. Krishnamurthy, A.S. Blum, F.W. Drislane, 3/2/2007, Technical implementation and clinical findings/results of monitoring oxygen saturation in patients referred for long term EEG monitoring, **Elsevier**, pp 432-439.

[32] Robert L . Trent, (1971), BIOMEDICAL SENSING AND DISPLAY APPARATUS, **Free Patents Online[Online]**, Patent No. 3623477 , pp.1-7.
http://www.freepatentsonline.com/3623477.pdf

[33] Jacques Martinerie, (2006), Analysis method and real time medical or cognitive monitoring device based on the analysis of a subject's cerebral electromagnetic use of said method for characterizing and differenting physiological and pathological states, **Free Patents Online [Online]**, Patent No. 20060015034 A1 , pp.1-5.http://www.freepatentsonline.com/20060015034.pdf

[34] Wang Jiongjiong, (2007), ASSESSING SUBJECT'S REACTIVITY TO PSYCHOLOGICAL STRESS USING FMRI, University of Pennsylvania, **World Intellectual Property Organisation**, Patent No. WO 2007/123799 A2, all pages.
http://www.wipo.int/pctdb/en/ia.jsp?ia=US2007%2F008065&IA =US2007008065&DISPLAY=STATUS

[35] Wrong diagnosis, 12/1/2009, Headache, **Wrong diagnosis**, p1.
http://www.wrongdiagnosis.com/h/headache/intro.htm

[36] Brunel university, (2005), A QFD Demo.Example, Harmonic design methodology, **Brunel QFD Software(Tower C) And design worksheets**, p 55.

[37] A: Textually.org, 21/11/2008 , Tele-medicine Mobiles, **Positive Technology Journal** , p1.http://gaggio.blogspirit.com/brain-computer_interface/.

[38] C, E : Ideal Tech Co.Ltd. , 16/3/2008 , watch cellphone and Blue tooth MP3 MP4 COOL WATCH, **Ideal Tech Co.Ltd.** , p1.http://ideatech.en .alibaba.com/product /50394197/202924228 /Mobile_Phone/watch _cellphone.html

[39] F: OneStepAhead, 12/9/2007 , Wrist Watch Walkie Talkie, **OneStepAhead,** pp1. http://www.onestepahead.com/catalog/product.jsp?productId=403801.

[40] G :Textually.org, 6/10/2008, Respiration Mobile, **Positive Technology Journal** , pp1.http://gaggio.blogspirit.com/brain-computer_interface/.

[41] Babs R. Soller, Marco Cabrera, Scott M. Smith, and Jeffrey P. Sutton, (2002) **,** Smart Medical Systems With Application to Nutrition and Fitness in Space ,**©Elsevier Science Inc.,** Nutrition Volume 18, Number 10, pp 930-936.

[42] Claude Hilbert, MCC, 29/1/2007 , MEMS/Microsystems devices and process technologies, **World Technology Evaluation Centre**, pp1. http://www.wtec.org/loyola/mcc/mems_eu/Pages/Chapter-5.html.

[43] Harvard Sensor Networks Lab, 2/2/2008, CodeBlue: Wireless Sensors for Medical Care And Wireless Vital Sign Sensors, **Harvard University Publications**, p1. http://www.eecs.harvard.edu/~mdw/proj/codeblue/.

[44**]** Gale, 5/7/2008 , Proponents of Tiny MEMS Computer Chips See Big Things for Industry, **Access my Library**, p1. http://www.accessmylibrary.com/coms2/summary_0286-7527483_ITM

[45] Yonghong Li, Wendong Zhang, Haifeng Dong, Jijun Xiong, Jun Liu, (2002) , Micro storage measurement unit, **Elsevier Science- Microelectronic Engineering 61 –62**, pp1039-1047.

[46] IEEE Virtual Museum, 13/4/2008 , IBM’s Millipede Memory Chip, **IEEE**, p1.http://www.ieee-virtual- museum.org/collection/tech.php?taid =&id=2345954&lid=1 .

[47] Matt Marshall, 2/9/2007, Emotiv’s brain joystick**, VentureBeat**, p1. http://venturebeat.com/2007/03/08/roundup-the-vc-tax-skypes-paid-calls-emotivs-brain-joystick/

[48] Emotiv, 2/9/2007, **Emotiv**, Emotiv’s brain joystick, p1. http://emotiv.com/INDS_2/inds_2_1.html.

[49] James Napier, 2/9/2007, OCZ prepares Neural Impulse Actuator **,Overclock3D Ltd,** p1.

,http://www.overclock3d.net/news.php?/input_devices/ocz_prepares_neural _impulse_actuator_for_shipping_next_week/1.

[50] MichaelVail, 7/12/2008, Wireless EEG system self-powered by body heat and light, **PHYSORG**, p1.
http://www.thought-criminal.org/article/node/1484.

[51] NeuroSky Inc, 7/12/2008, Product Summary, **NeuroSky Inc**, p1.
http://www.neurosky.com/menu/main/technology/product_summary/.

[52] Dan-hua Zhu, Ji-jun Tong and Yu-quan Chen, (2008), An ICA-based Method for Automatic Eye Blink Artifact Correction in Multi-channel EEG, **IEEE EXPLORE - 5th International Conference on Information Technology and Application in Biomedicine**, pp338-3340.

[53] Gyroscope, 1/3/2007, gyroscopes photos, **Photos Site**, p1.
http://www.me.umn.edu/labs/advcontrols/pics/GyroscopePCB.jpg

[54] Hongwei Qu, (2008), A Monolithic CMOS-MEMS 3-AxisAccelerometer With a Low-Noise,Low-Power Dual-Chopper Amplifier, **IEEE SENSORS JOURNAL**, VOL. 8, NO. 9, pp 1511-1517.

[55] Wikipedia, 19/8/2008**,** Infrared thermometer, **Wikipedia Online Encyclopaedia** , p1. http://en.wikipedia.org/wiki/Infrared_thermometer .

[56] Warring et al., (1995), Methods and devices for facilitated non-invasive oxygen monitoring, **Free patents online** [Online], Patent No. 5402777: pp.1-11
http://www.freepatentsonline.com/5402777.html

[57] Clark et al., (1992), Non-invasive system and method for enhanced arterial oxygen saturation determination and arterial blood pressure monitoring**, Free Patents Online** [Online], Patent No. 5111817: pp.1-17.
http://www.freepatentsonline.com/5111817.html

[58] Amazon, 3/12/2007, MIO Shape Heart Rate Monitor Watch, **Amazon Items,** p1.http://www.amazon.com/exec/obidos/ASIN/B00009MKC4/becomecom-20/ref=nosim

[59] Wen-Yang Chang, Chun-Hsun Chu, and Yu-Cheng Lin, (2008), A Flexible Piezoelectric Sensor for MicrofluidicApplications Using Polyvinylidene Fluoride, **IEEE SENSORS JOURNAL**, VOL. 8, NO. 5, pp 495-499.

[60] Pavel Neuzil and Ting Mei, (2004), A Method of Suppressing Self-Heating Signal of Bolometers, **IEEE SENSORS JOURNAL**, VOL. 4, NO. 2, pp207-210 .

[61] Edson Gomes Camargo, (2007), High-Sensitivity Temperature Measurement With Miniaturized InSb Mid-IR Sensor, **IEEE SENSORS JOURNAL**, VOL. 7, NO. 9, pp1335-1338.

[62] Yves Moser and Martin A. M. Gijs, (2007), Miniaturized Flexible Temperature Sensor, **JOURNAL OF MICROELECTROMECHANICAL SYSTEMS**, VOL. 16, NO. 6, pp 1349-1353.

[63] Brunel university, (2008), IR Thermometers And Pyromrters, **Omega.com HOME** , p 1.Z:\Mphil 2008\Brunel university\literature\IR thermometer\pyrometer.html.

[64] Olgaç Ergeneman, (2008), A Magnetically Controlled Wireless Optical Oxygen Sensor for Intraocular Measurements, **IEEE SENSORS JOURNAL**, VOL. 8, NO. 1, pp29-35.

[65] Robert H Nixon, (2003), Photodiode Light Sensor, **Patent Storm[Online]**, Patent No. 6504142, pp .1-24.http://www.patentstorm.us/patents/6504142-claims.htmlpp

[66] Maplin electronics company, 3/1/2007, Phototransistor – photodiodes-infrared sensors**, Maplin**[Online], p1. http://www.maplin.co.uk/Search.aspx?SD=false&C=gkw&Criteria =INFRARED%20SENSOR&U=INFRARED%20SENSOR&T=2005437&gclid=CIWxysz7yosCFSoMQgod_EHzH

[67] Fábio Durante P. Alves, (2008), Widely Separate Spectral Sensitivity QuantumWell Infrared Photodetector Using Interband and Intersubband Transitions, **IEEE SENSORS JOURNAL**, VOL. 8, NO. 6, pp 842-847.

[68] Johannes A. Kalb, Qiang Guo, Xiaoqiang Zhang, Yi Li, Chornghaur Sow, and Carl V. Thompson, (2008), Phase-Change Materials in Optically Triggered Microactuators, **JOURNAL OF MICROELECTROMECHANICAL SYSTEMS,** VOL. 17, NO. 5, pp 1094-1102.

[69] Marcus Yam, 5/5/2008 , Phase Change Memory Technology May Succeed Flash, **DailyTech**, p1. http://www.dailytech.com/article.aspx?newsid=5313&commentid=87424&threshhold =1&red=3039 .

[70] Images, 7/12/2008, Nanotube memory, **Photo Site**, p 1. http://uk.images.search.yahoo.com/search/images?_adv_prop=image&fr=yfp-t-501&va=nanotube+memory&sz=all

[71] IBM Zurich Research Laboratory, 4/6/2008, Millipede small scale MEMS prototype shown at CeBIT, **PHYSORG**, p1. http://www.physorg.com/news3361.html.

[72] Brain Research Center, 13/7/2007, Mobile & Wireless BCI, **Brain Research Center**, p1. http://sccn.ucsd.edu/~jung/bci.html.

[73] Rachel A. Yotter, (2004), Sensor Technologies for Monitoring Metabolic

Activity in Single Cells—Part I: Optical Methods, **IEEE SENSORS JOURNAL**, VOL. 4, NO. 4, pp395-408.

[74] Yanko Design, 7/12/2008, Projection Mobile Phones, **Yanko Design,** p1. http://www.yankodesign.com/index.php/2007/10/16/projection-mobile-phones/.

Bibliography

1) Imperial college, MEMS research books (Brunel-Imperial cooperation), MEMS sensors chapters.
2) Brunel University, Engineering Design Course, course notes, Harmonic Unity of Product components Concept.
3) Mark J.Schulz, (2006), Nanoengineering of structural, functional, and smart materials - Taylor and Francis Group - pp 1-5, 361,363,preface.
4) Yoji Akao, (1990), QFD Integrating Customer Requirements into Product design, Productivity Press, pp1-25, 83-100.
5) Phaidon Press Limited, (2002), SPOON (Product design concepts), pp186.
6) Satoashi Kawata, (2002), Nano Optics, Springer, pp224-227.
7) T .Holroyd, (2000), Acoustic Emission & Ultrasonics, Coxmoor Publishing co., pp 30.
8) John Dakin and Brian Culshaw, (1988), Optical-Fibre Sensors, Artech House Inc., pp154-160.
9) P.L Hurricks, (1994), Electromechanical Product Design, Longman Group, pp1-17, 24-27 , 37 .
10) S . Middelhoek, (1998), Handbook of Sensors and Actuators (volume 6), Elsevier, pp 170, 171.