DEVELOPMENT OF A PC INTERFACED BLOOD PRESSURE METER

(E-BPMS)

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ABSTRACT

Blood pressure is one of the fundamental vital signs, and its measurement is of great importance to medical professionals and the general public alike. Nowadays, there are several types of blood pressure meter available manufactured from various companies. In order to meet the demand on telemedicine and technology advancement, a new form of blood pressure meter is desirable. This prototype of blood pressure meter is interfaced with a personal computer (PC) which able to simulate the measurement process in real time. The proposed system was named e-BPMS (Electronic Blood Pressure Measurement System) suggests the usage of both hardware and software in determining blood pressure reading. Hardware elements operate on oscillometric principle which gives the results in terms of systolic, diastolic and MAP (Mean Arterial Pressure). Furthermore, these results will be presented and simulated on the software. The e-BPMS interface was developed by using Visual Basic 6.0 language which highlights the user friendly attributes. Moreover, the simulated waveform will evaluate the blood pressure and gives the blood pressure value. This application shows significant improvement on the overall performance and gives reliable results. The framework used to design e-BPMS is easy to understand and it can be extended further to endorse new application area.

ABSTRAK

Tekanan darah merupakan suatu penanda asas bagi mengetahui status kesihatan pesakit oleh pengamal perubatan atau orang awam dan pengukurannya adalah penting bagi mengetahui tahap kesihatan. Kini, terdapat pelbagai jenis alat mengukur tekanan darah yang beroperasi menggunakan teknik-teknik yang berlainan dikilangkan oleh pelbagai pengeluar. Kepesatan perkembangan teknologi pada masa ini untuk mencapai aplikasi Tele-Perubatan menyebabkan keperluan untuk mencipta satu alat mengukur tekanan darah yang baru meningkat. Projek ini bertujuan untuk mencadangkan satu alat mengukur tekanan darah yang baru menggunakan prinsip osilometrik di mana ianya dihubungkan dengan komputer peribadi dan boleh mamaparkan simulasi bagaimana tekanan darah seseorang ditentukan. Prototaip alat mengukur tekanan darah ini dinamakan e-BPMS iaitu singkatan untuk "Sistem mengukur tekanan darah elektronik". Sistem ini boleh dibahagikan kepada dua elemen iaitu "hardware" dan juga "software". Keluaran akan memberikan keputusan analisis dalam bentuk bacaan sistolik, diastolik dan juga purata tekanan arteri. Semuaa bacaan yang dipaparkan adalah menggunakan perisian bahasa pengaturcaraan "Visual Basic 6.0" . Projek ini telah berjaya memberi keputusan yang dikehendaki dan berjaya memenuhi objektif dan ianya boleh diperbaiki lagi di masa akan datang.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Blood pressure is one of most important measurements which indicate person's health condition. Abnormal blood pressure reading may lead to various diseases which can be prevented by treatment. Blood pressure related diseases are usually being referred as "silent killer". The consequence promoted can be either cardiac disorder or the malfunctions of our body systems. Considering these huge effects may be too harmful for human body, thus preventive action needs to be taken. High blood pressure is an epidemic disease which always a major concerns in developed countries.

Statistic shows the great number of cases for the past decades, which triggers the insight to prevent and control this disease rather than cure it. Nowadays, the need for a reliable medical technologies and analysis is desirable, since the users prefer to experience their medical diagnosis themselves. Home monitoring provides an accurate record of measurements over time helps in planning an overall personal health regimen. Furthermore, blood pressure management is a step towards a healthier lifestyle.

1.2 Theory

1.2.1 Blood Pressure

Blood pressure is defined as the pressure of the blood against the walls of the arteries. It is the resultant of two forces. One is created by the heart as it pumps blood into the arteries and through the circulatory system. The other is the force of the arteries as they resist the blood flow. This phenomena can be illustrates as in figure below.

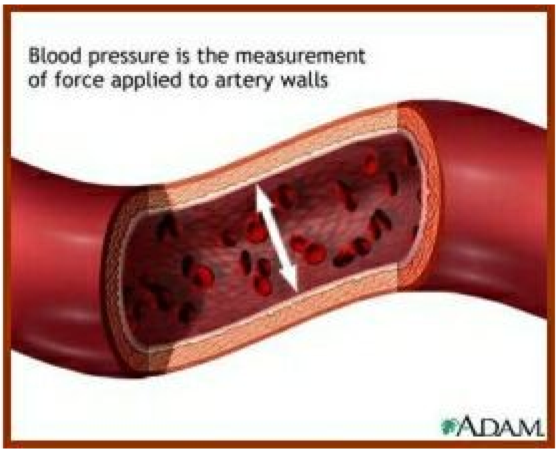

Figure 1.1: Measurement of force applied to artery walls

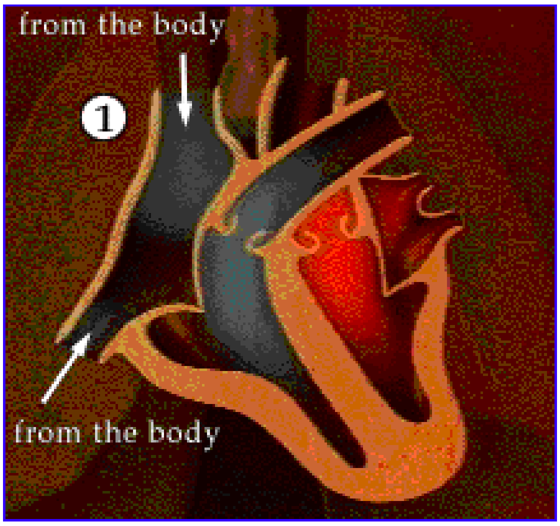

Figure 1.2: Blood circulation in the heart

Blood pressure is measured in millimeters of mercury (mmHg) and recorded as two numbers systolic pressure "over" diastolic pressure. For example, the doctor might say "130 over 80" 130/80 mmHg as a blood pressure reading. The measurement is taken when the doctor puts the cuff around patient's arm and pumps it up. The pressure exerted by the cuff will block the blood flow in the vessel. As the pressure is released slowly, blood starts to flow again and the doctor can hear the flow using a stethoscope. The number at which blood starts flowing again is recorded as maximum output of pressure of the heart (systolic). Then, the doctor will continue releasing the pressure of the cuff and listens until there is no sound. The number (80) indicates the pressure in the system when the heart is relaxed (diastolic).

According to American Heart Association (AHA), optimal blood pressure with respect to cardiovascular risk is less than 120/80 mmHg. However, unusually low readings should be evaluated to rule out medical causes. If the patient exhibits low readings every measurements, there is a potential of having low blood pressure (hypotension). The systolic pressure of 120 to 139 mmHg or diastolic pressure of 80 to 89 mmHg is considered as at risk of having high blood pressure (pre hypertension). Furthermore, blood pressure reading of 140/90 mmHg is considered elevated high (hypertension). The range of blood pressure recommended by AHA is summarized in the Table 1.1 below.

Table 1.1: Blood pressure range

Category	Systolic (mmHg)	Diastolic (mmHg)
Normal	< 130	<85
High Normal	130-139	85-89
Hypertension		
Stage 1 (mild)	140-159	90-99
Stage 2 (moderate)	160-179	100-109
Stage 3 (severe)	108-209	110-119
Stage 4 (very severe)	≥210	≥120

Blood pressure reading is known to be varied between one people to another. It is recommended by AHA that ideally, blood pressure must be checked at least twice a year and it should be more often if it is high. Some of the factors affecting blood pressure can be classified into several categories concerning physiological, gender, lifestyles and many others. The elaboration of these factors will be in following section.

1.2.2 Blood Pressure Instruments

Traditionally, a sphygmomanometer is used for measuring blood pressure in the arteries. The word is derived from the Greek "sphygmus" (pulse), plus the scientific term manometer was introduced by Scipione Riva Rocci, an Italian Physician during 1896. A sphygmomanometer usually consists of an inflatable cuff, a measuring unit (the mercury manometer), a tube to connect the two, and (in models that don't inflate automatically) an inflation bulb also connected by a tube to the cuff. The inflation bulb contains a one-way valve to prevent inadvertent leak of pressure while there is an adjustable screw valve for the operator to allow the pressure in the system to drop in a controlled manner. Presently, there are many types of sphygmomanometer that have being used for clinical practices such as electronic sphygmomanometer, conventional sphygmomanometer and aneroid sphygmomanometer as shown as in figure 1.3, figure 1.4 and figure 1.5 below.

Figure 1.3: Electronic sphygmomanometer

Figure 1.4: Conventional sphygmomanometer

Figure 1.5: Aneroid sphygmomanometer

Due to technologies advancement, blood pressure testing devices now are using electronic instruments or digital readouts. In these cases, the blood pressure reading appears on a small screen or is signaled in beeps, and no stethoscope is used. Most of digital instruments have an automatic inflation mechanism, which replace the manual inflation bulb for simplicity and comfort. A digital system is widely known for its convenience and robustness even in noisy environment is preferable. Therefore, blood pressure meter now available is still adapting the same measuring techniques with added features. Some of available blood pressure meter are tabletop, wristband and also finger. Considerations need to be made when designing a digital blood pressure meter since electronic devices are very susceptible to operating temperature and also humidity.

1.2.3 Important of Blood Pressure

High blood pressure is a very common condition in modern society. It has been estimated that one in five Americans, around 50 million people, suffer from high blood pressure. In general more men than women have high blood pressure, and the number of sufferers of both genders increases rapidly with age. In around 5% of cases of high blood pressure is caused by kidney problems, but the causes of the other 95% of cases are unknown. There are a number of factors such as race, age, obesity, stress, smoking and lack of exercise that can contribute to the likelihood of a person developing high blood pressure but usually no one cause is directly responsible. The majority of people with high blood pressure experience no symptoms, but if left untreated high blood pressure can lead to major health problems.

Consequently the monitoring of blood pressure is vitally important in order to detect cases of high blood pressure and treat them early before health problems can develop. Prolonged high blood pressure damages the lining of artery walls, making them thick and stiff. This condition is known as arteriosclerosis. Cholesterol is more likely to cling to the damaged artery walls, narrowing the arteries and thus preventing the blood from flowing through the body properly. The heart has to work harder to compensate for the narrowed arteries. Over time this causes the heart to thicken and stretch, eventually failing to function normally, and causing fluids to back up into the lungs. If the heart cannot work hard enough to compensate for the narrowing of the arteries then less blood can get around the body. Reduced blood flow to the heart can cause chest pain and angina, and eventually the flow may be stopped completely, causing a heart attack.

The function of the kidneys is to filter waste from the blood, but if blood flow to them is reduced then they become less efficient and waste builds up in the blood. Eventually they may fail completely, and dialysis or a kidney transplant will be required. High blood pressure can also lead to brain damage and impaired vision. If a blood clot occurs in one of the narrowed arteries leading to the brain a thrombotic stroke may occur. Alternatively the weakened blood vessels in the brain may break due to the high pressure leading to hemorrhagic stroke. A 25-year study of 11,000 individuals has confirmed that young men with high blood pressure are more likely to die from heart disease or other causes than those with normal blood pressure, translating to an estimated shorter life expectancy of two to four years. The researchers called for increased population-wide prevention of increased blood pressure through healthy lifestyle habits and efforts to detect rising blood pressure in children, teenagers and young adults so that control of blood pressure can be started early.

1.3 **Method of Blood Pressure Measurement**

There are few available techniques employed for blood pressure measurements in which have their own strengths and weaknesses. Two popular approaches can be classified into two major groups known as invasive and non-invasive methods. As the name implies, invasive method involve catheterization (cut) where the patient need to undergone a minor surgical process. On the other hand, the non invasive technique offers simplicity, convenience, and comfort procedure to the patient is more preferable.

The invasive method is undoubtedly yields the most accurate measurements, but it is rarely used since it is more risky and patient may suffer excessive blood loss. Even today, invasive catheterization procedures are seldom used due to the risk of infection. Although, non invasive sacrifice a degree of accuracy in the measurement, the procedures which are considering for patient safety are widely applied. Two major methods for non invasive measurement are known as Auscultatory and

Oscillometric. In fact, there are various methods used for measuring blood pressure which will be discussed next.

1.3.1 Direct Techniques

The operation of direct measurement techniques can be summarized in very simple terms which they all utilize a pressure transducer that is coupled to the vascular system through a catheter or cannula that is inserted to a blood vessel, followed by a microcontroller unit with electronics and algorithms for signal conditioning, signal processing and decision making. There are many advantages of this set of techniques, including:

i. the pressure is measured very rapidly, usually within one cardiac cycle.
ii. the measurement is done to a very high level of accuracy and repeatability.
iii. the measurement is continuous, resulting in a graph of pressure against time.
iv. the measurement is motion tolerant.

Therefore, the direct techniques are utilized when it is necessary to accurately monitor patients' vital signs, for example during critical care and in the operating room. Although direct techniques have a lot in common, there are differences in the details of various approaches. Extravascular transducers is one the direct technique that have being used in blood pressure measurement. According to this technique, the catheter in this type of devices is filled with a saline solution, which transmits the pressure to a chamber that houses the transducer assembly. As a minor disadvantage, this structure affects the measured pressure through the dynamic behavior of the catheter. Since the catheter has a known behavior, this effect can be minimized to insignificant levels through computational compensation (Gibbs).

Another direct technique is intravascular transducers. The transducer is at the tip of the catheter in this type of devices. Then, the measured signal is not affected by the hydraulics of the fluid in the catheter. The catheter diameter is larger in this class of transducers. The new technique of direct measurement is by using transducer technology where there is a wide spectrum of transducer technologies available to build either kind of transducer. They include metallic or semiconductor strain gages, piezoelectric, variable capacitance, variable inductance, and optical fibers. Appropriate driver and interface circuitry accompanies each technology (Webster, pp. 44-88). One of the advantage of direct measurement techniques is that, they are not limited to measuring the simple arterial pressure. They can be used to obtain central venous, pulmonary arterial, left atrial, right atrial, femoral arterial, umbilical venous, umbilical arterial, and intracranial pressures, by inserting the catheter in the desired site (Hambly). Blood pressure waveform can be performed as shown as in figure 1.6 below.

Figure 1.6: Blood pressure waveform, and systolic, diastolic, and mean pressures, from an invasive monitor screen. (Philips).

As time goes by, direct technique are not being used due to some errors [1]. Direct blood pressure measurement systems have the flexibility of working with a variety of transducers/probes. It is important that the probes are matched with the appropriate compensation algorithm. Most of the modern equipment does this matching automatically, eliminating the possibility of operator error. An additional source of error occurs when air bubbles get trapped in the catheter. This changes the fluid dynamics of the catheter, causing an unintended mismatch between the catheter and its signal processing algorithm. This may cause distortions in the waveforms and errors in the numeric pressure values extracted from them. It is difficult to recognize this artifact from the waveforms, so it is best to avoid air bubbles in the catheter.

1.3.2 Indirect Techniques (Non-invasive)

Blood pressure measurements obtained by non-invasive methods are an indispensable procedure for evaluating and treating patients in a medical environment. This procedure has been implemented in some ways almost automatic, mainly with the use of equipments based on the oscillometric method, illustrated in Figure 1.7 [1].

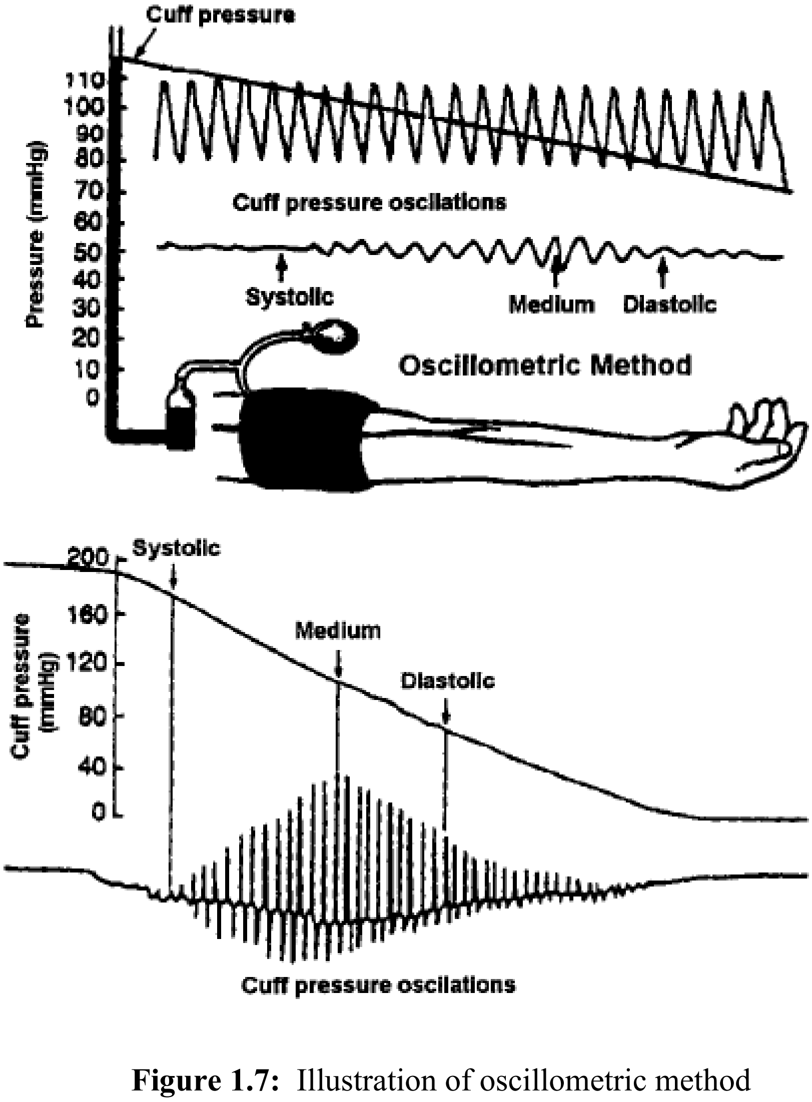

Figure 1.7: Illustration of oscillometric method

An overwhelming majority of blood pressure measurements do not require continuous monitoring or extreme accuracy. Therefore non-invasive techniques are used in most cases, maximizing patient comfort and safety. Currently available devices for noninvasive measurement are:-

i. Manual devices: these devices use the auscultatory technique.

ii. Semi-automatic devices: these devices use oscillatory techniques.

iii. Automatic devices: while a majority of these devices use oscillatory techniques, there are some that use pulse-wave velocity or plethysmographic methods.

1.3.2.1 Auscultatory Method

The auscultatory method is the original technique that has been used by many doctors and remains the most common method of measuring NBP today [2]. It is based on the principle of manually inflating a cuff around the arm (typically), occluding the brachial artery, slowly releasing the occlusion, and listening for Korotkoff sounds. Korotkoff sounds are caused by the hammering of the blood against the arterial wall when the compression of the artery is released. The onset of Korotkoff sounds denotes the systolic pressure while the complete disappearance of Korotkoff sound signifies the diastolic pressure [3]. Figure 1.8 below can illustrate how systolic and diastolic pressure are obtained.

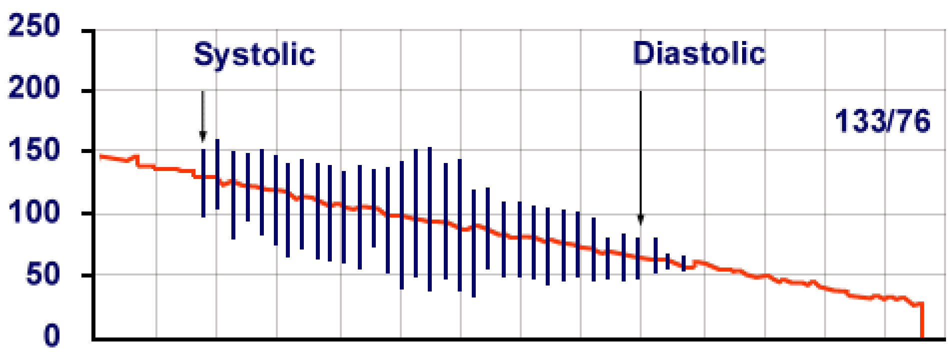

Figure 1.8: Determination of blood pressure by using auscultatory.

1.3.2.2 Oscillatory Method

The oscillometric method of measuring is used in most bedside patient monitors and although there are some variances between manufacturers, the principle method is the same. With this technique, a cuff is also applied to the patient's arm or leg and is inflated to a point above their systolic pressure, subsequently occluding blood flow through the artery. In Dräger Medical's Infinity patient monitors, the cuff is then deflated at various pressure levels, allowing blood to flow back through the artery in steps (Figure 1.9(a) and Figure 1.9(b)).

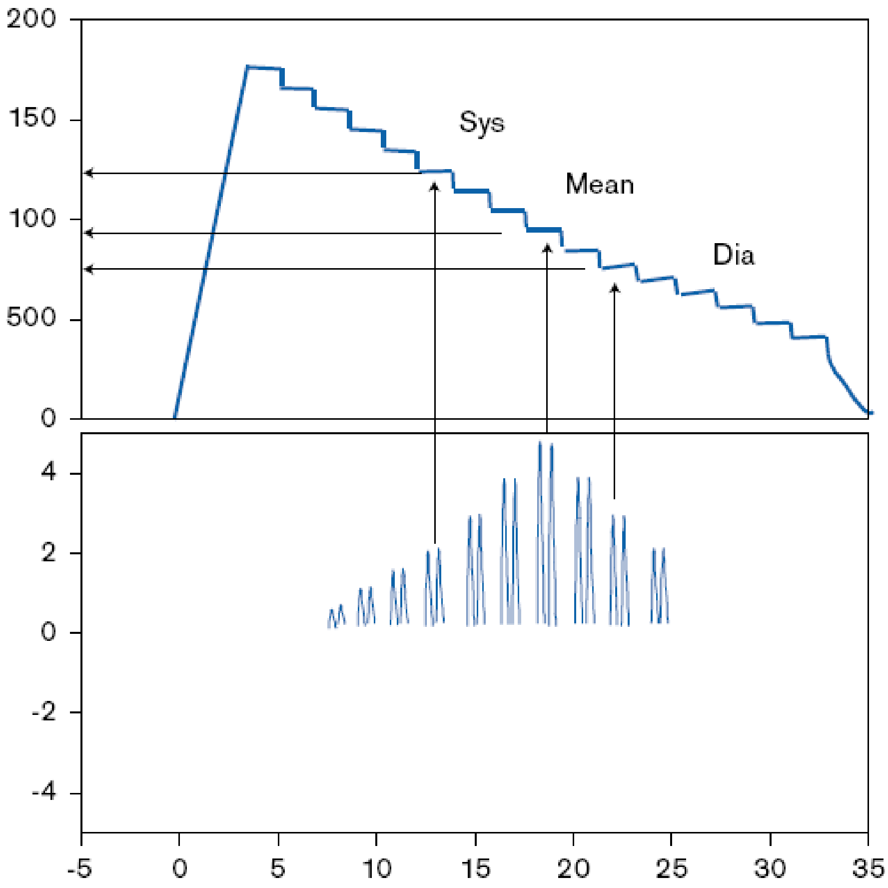

Figure 1.9: (a) Stepped deflation cuff pressure (upper trace).
(b) By zooming in on the cuff pressure, the small oscillations

generated by blood flow through the arteries, are visible (lowertrace). The peak oscillation corresponds to the Mean Arterial Pressure.

As the pressure in the cuff is reduced, the blood pressure pulses within the artery distend the soft tissues of the limb. These fluctuations in arm circumference cause pneumatic pressure oscillations in the cuff, which can be sensed by transducers within the monitor. During the cuff deflation, the onset and increase of oscillations denotes the supra-systole region. The maximum oscillation sensed indicates the mean blood pressure pulse, while the diastole region is marked by a decrease and disappearance of oscillations.

The NBP monitor deflates the cuff one step each time it detects two oscillations of relatively equal amplitude ('peak detection'). The time between deflation steps depends on the frequency of these matched pulses. However, if the NBP monitor is unable to find a pulse within several seconds, it will deflate to the next step. The process of finding two matched oscillations at each step provides artifact rejection due to patient movement and greatly enhances accuracy. The arterial waveform of blood pressure by using oscillometry method as shown as in figure 1.10 below.

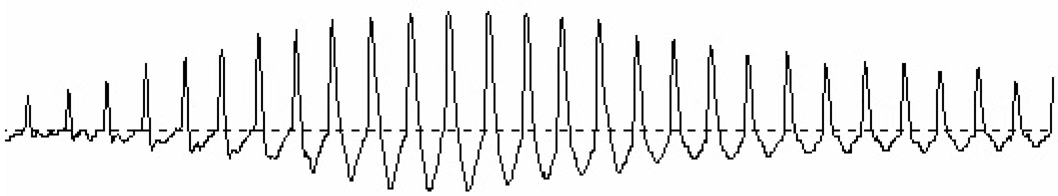

Figure 1.10: Blood pressure waveform by using oscillometric method.

1.3.2.3 Automated Auscultatory Technique

These devices apply sound-based algorithms to estimate SBP and DBP. By using a microphone, these devices lack validation ability. In addition to noise-artifact sensitivity, these sound-dependent algorithms may not adequately compensate for patient conditions such as hypotension (i.e. low blood pressure), where the Korotkoff sounds may be muted. To make automated measurement more reliable, oscillometric devices were created.

1.3.2.4 Tonometry Technique

This method uses a different approach where the arterial tonometry is realized by flattening the pressure non invasively to squeeze the artery against bone. The applied pressure required to maintain the flattened shape are recorded and accomplished by using array of pressure sensors. An algorithm must be used to calculate the blood pressure from the waveform obtained. Moreover, the waveform exhibits a similar pattern as catheter measurement (invasive). However, tonometry have several limitations which affecting its performance. Limitations like high sensitivity to sensor position and angle, measuring peripheral circulation, low inter operator reproducibility, and is also requires regular calibration.

1.3.2.5 Infrasound and Ultrasound Technique

Infrasound technique attempts to improve on the auscultatory method by detecting the low frequency Korotkoff sound vibrations below 50 Hz, in which including sub audible vibrations. On the other hand, ultrasound technique is not commonly used for measuring blood pressure. Usually, it is use in combination with other methods. Major feature of this method is, the values recorded by using ultrasound can be very operator dependent.

1.3.2.6 Ambulatory Blood Pressure Monitoring Technique

Ambulatory blood pressure monitoring (ABPM) is a method of taking regular blood pressure readings of patients as they conduct their normal daily activities. Although generally used for 24 hours, ABPM can also be used for up to 48 hours if necessary. Blood pressure is a measure of the force, or tension, of the blood in the walls of the arteries. High blood pressure (hypertension) puts an added workload and strain on the heart, while low blood pressure (hypotension) can lead to fainting (syncope). Blood pressure is measured with the use of an arm cuff (sphygmomanometer) and expressed as systolic pressure over diastolic pressure. Systolic pressure is the highest level of the blood's pressure within the artery walls and corresponds to the contraction of the ventricle. Diastolic pressure is the lowest pressure at which blood stays within the aorta.

Blood pressure is measured by either a clinic reading taken at a doctor's office or a patient self-test with a personal BP monitor or public equipment (such as are found in most pharmacies). Both the clinic reading and the self-test BP are considered "casual" readings. Different monitors may be used, and tests may be completed at different times of day. For most patients, this casual BP is all that is needed to monitor current blood pressure diagnoses or to help detect the presence of blood pressure disorders. However, some conditions are more difficult to diagnose or monitor. When these conditions are present, ambulatory blood pressure monitoring (ABPM) may be useful. Figure 1.11 below shows an instrument for ABPM.

Figure 1.11: Blood pressure instrument for ABPM

1.3.2.7 Finger Cuff Technique

Invasive beat-to-beat arterial blood pressure monitoring is considered the 'gold standard', as it is both accurate and reliable. However, cannulation of radial artery is associated with a risk of local infection, haematoma formation, or thrombosis. Therefore, non-invasive method providing accurate and reliable data are required. In 1973, Penaz described the volume clamp technique whereby a continuous non-invasive arterial pressure waveform could be obtained from a finger cuff [5]. The blood volume of the finger varies in clinical fashion with each cardiac cycle because of the attendant variation in systemic blood pressure. This variation is detectable by a plethysmograph attached to the finger. If a pneumatic finger cuff can be inflated and deflated rapidly enough to maintain constant finger blood volume then the arterial wall has been 'unloaded' i.e. the cuff pressure must be equal to the intra-arterial pressure.

A display of the cuff pressure should, therefore, represent the intra-arterial pressure waveform of the digit and the analysis of the cuff waveform would allow measurement of systolic, diastolic, and mean blood pressure. The principles have been embodied in the Finapres and with modifications in the Portapres. Finger blood pressure measurement is an advance in the monitoring of patients admitted to the emergency department. However, a final comment on its use in intensive care units is not possible due to the lack of data.

1.3.2.8 Pulse Dynamic Technique

Pulse wave is generated by the heart as it pumps blood, and travels ahead of the pumped blood. By solving analytical equations of fluid dynamics, it has been shown that changes in blood pressure heavily depend on changes in pulse wave velocity. Blood pressure can be continuously calculated from pulse wave velocity, which in turn is calculated from EKG parameters and peripheral pulse wave measured by an SpO2 probe on the finger or toe. This method is suitable for continuous monitoring, as well as for detecting sudden changes in blood pressure to trigger an oscillometric cycle (Williams).

1.3.2.9 Plethysmography Technique

In this method, changes in the blood volume during a cardiac cycle are sensed using a light emitter and receiver at the finger. Tissue and blood have different infrared light absorbance characteristics. That is, the tissue is practically transparent to the infrared light, while blood is opaque to it. A prototype of a ring-like sensor/signal processor/transmitter combination has been reported (Yang), (Rhee).

1.4 **Problem Statement**

Nowadays most of the people are reluctant to get their blood pressure being checked regularly. Usually, when they experience the diseases then only they would seek for professional helps. As we know blood pressure diseases are harmful to human for instance high blood pressure (hypertension) and low blood pressure (hypotension). Driven by this consensus, human desires a simple and reliable blood pressure measurement instruments which can suits their lifestyle. Due to technology advancement, blood pressure instruments come in variety of sizes equipped with added functions. To meet these requirements, a simple low cost digital blood pressure meter which can do a real time analysis will be introduced. In the project, a computer is use because it has a large memory space to store abundant of data. Therefore, PC can work as a platform for interaction for blood pressure monitoring system.

1.5 **Projects Objectives**

Objectives of this project are :-

i. To develop a digital blood pressure meter to be interfaced with a personal computer (PC).
ii. To display blood pressure measurement with graph view to PC.
iii. To introduce an affordable, low cost and user friendly digital blood pressure monitor.

1.6 Importance of Project

The development of PC based digital blood pressure meter was designed purposely to introduce an alternative way to promote regular self monitoring for patient. User of this project may experienced themselves for simple blood pressure screening procedures, which is done in real-time to check their health status. Therefore, a robust medical checking system is important to ensure the procedure can be done with a minimal supervision. It can be done by ourself. This is an innovation to help users execute the diagnosis all by themselves. By using this system, user is no need go to hospital for checking their blood pressure and infacts they are able to monitor their health status regularly. When e-BPMS is set ready for use, this device not only will help people to get their blood pressure measured regularly, this indirectly may promote early prevention due to blood pressure diseases. Presently many of deadness caused by blood pressure diseases.

1.7 Thesis Structures

Chapter I gives a brief introduction to the theory and measurement techniques of blood pressure. Next, this chapter tells reader the objectives of the thesis, scope of the project, the importance of project and also problem statements.

Chapter II discusses more about the detail of the fundamental theory of blood pressure measurement technique using oscillometric method. This includes the principle of oscillometric , the strategy of determination systolic and diastolic measurement, accuracy and method design.

Chapter III explains detail of methodology including hardware and software. This chapter will touch the overall design and assembling of e-BPMS, flowchart and process design.

Chapter IV explains the construction of the every single part of the e-BPMS hardware system from the pressure sensor, operational amplifier, filter circuit and then to a microcontroller control unit.

Chapter V gives an overview of the software development such as assembly language written by using MPLAB in order to program the microcontroller. Next, a program which has the ability to reconstruct the image written by using Visual Basic and subsequently discussing image reconstruction algorithm used in this project and acquisition methods used.

Chapter VI details out the results obtained by the system where some experiment were carried out to investigate the capability of the system. Other than that comparison of the performance of e-BPMS and other blood pressure measurement system. The accuracy of e-BPMS can be improved by selecting a suitable point of reference in VB programming to ensure the blood pressure was taken properly.

Chapter VII comes to end of discussion on the project, this section concludes the overall finding of the project, problems facing throughout the project. Most important is suggestions for future development to improve the overall performance of this project.

REFERENCES

1. Webster J.G, *Medical Instrumentation, Application and Design*,. 2nd Ed*.,* USA: Brooks/Cole Publishing Company, 1992.

2. Raghbir Singh, *Biomedical Instrumentation Technology and Application*, McGraw Hill, 2003

3. Tatsuo Togawa, Toshiyo Tamura, P. Ake Oberg, *Biomedical Transducers and Instruments*, CRC Press, 1991

4. Chua, C.S. and Siew, M.H., *Digital Blood Pressure Meter*. Singapore: Freescale Semiconductor Incorporated,1997

5. Fung, P., et. al. (2004). ,*Continuous Noninvasive Blood Pressure Measurement by Pulse Transit Time*. Proceedings of the 26th Annual International Conference of the IEEE EMBS. 738–741.

6. C.S. Chua and Siew Mun Hin, *Digital Blood Pressure Meter Sensor Application Engineering,* Singapore, A/P.

7. Lucas, Bill (1991), *An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor,*Freescale Application Note AN1305

8. Coleman AJ, Steel SD, Ashworth M, Vowler SL, Shennan A., *Accuracy of the pressure scale of sphygmomanometers in clinical use within primary care*. Blood Pressure Monitoring 2005 Aug:10(04): 181-8.

9. ABC of Hypertension, 4th edition published by BMJ Books and reviewed in BMJ 2001; 322:981-985.

10. K.G, Ng and C.F, Small, *Survey of Automated Non Invasive Blood Pressure Monitors,* Journal of Clinical. Engineering., 1994, vol. 19, pp 452- 475.

11. S.Mieke, H.Grob, M.Ulbrich, G.Papadopoulus and U.Frucht, *Non Invasive Blood Pressure Measurement*, Anaesthesist., 1993, vol. 42, pp 38 – 43.

12. J.N, Amoore, W.B, Geake and D.H.T, Scott, *The Effect Of Pulse Rate, Artefact And Pulse Strength On Oscillometric Non Invasive Blood Pressure Measurement,* Proceeding of the 1996 IEEE International. Conference .in Medical and Biology Society, Amsterdam, IEEE, 1996.

13. M.W, Millar Craig, *Ambulatory Blood Pressure Recording*; *Principles and Practice*, IEEE, Savoy Place, London, pp 311-312, 1998.

14. J.W, Miao, *A Computer Aided Method For Design Of Non Invasive Indirect Measurement Of Arterial Blood Pressure,* IEEE International Proceeding on Medical Instrumentation, October 1992.

15. K.Yamakoshi, A.Kamiya, H.Shimazu, H.Ito and T.Togawa, *Non Invasive Automatic Monitoring of Instantaneous Arterial Blood Pressure Using The Vascular Unloading Technique,* Journal of Medical & Biology. Engineering & Computing, no 21,1983, pp 557-565.

16. W.B, Geake, J.N, Amoore and D.H.T Scott, *An Automated System for The Functional Evaluation of Oscillometric Non Invasive Blood Pressure Monitors,* Journal of Medical. Engineering & Technology, vol 19, 1995, pp 162-176.

17. Takao Wada, Kiyoyuki Narimutu, *Non Invasive Technique for Analysis of Feedback Relationship Between Heart Rate and Beat–to-Beat Blood Pressure Fluctuations,* IEEE International Proceeding on Statistical Modeling, 1994, pp 1260-1261.

18. R J, Riggs, *Use of Database to Develop Algorithms for Ambulatory Blood Pressure Measurement*, Abingdon: Oxford Medical Ltd, pp 100-103, 1996.

19. Michael J. Randall, Jean Pierre DeJean and Jack W. Frazer, *Computer Automation of Blood Pressure Measurement*, International. Proceeeding of IEEE*, Oct 1975*, pp 1399-1403.

20. S. Colak and C. Isik, *Fuzzy Oscillometric Blood Pressure Classification*, 10th Annual International Conference of IEEE Engineering in Medicine & Biology Society, 2003, vol 13, pp 208-213.

21. JCTB Moraes, M Cerulli and PS Ng, *A Strategy for Determination of Systolic, Mean and Diastolic Blood Pressures from Oscillometric Pulse Profiles*, International Conference of IEEE in Computers in Cardiology, 2000, pp 211-214.

22. JCTB Moraes, M Cerulli and PS Ng Development of a New Oscillometric Blood Pressure Measurement System, *International Conference of IEEE in Computers in Cardiology*, 1999, pp 467-470.

23. Michael J. Randall, Jean Pierre DeJean and Jack W. Frazer Computer

Automation of Blood Pressure Measurement, *International Proceeeding of IEEE*, Oct, 1975, pp 1399-1403.

24. R.M, Rangayyan, *Biomedical Signal Analysis: A Case Study*, New Jersey: IEEE Press, 2002.

25. Dogan Ibrahim, *PIC Basic: Programming and Projects*, Oxford: Newnes, 2001.

26. G.D, Baura, *System Theory and Practical Applications of Biomedical Signals*, USA: John Wiley & Sons INC, 2002.

27. OMRON, *Automatic and Manual Blood Pressure Monitors*, available at http://www.omronhealthcare.com, 2003. Accessed on 5th February 2006.

28. CITIZEN, *Digital Blood Pressure Meter*, available at: http://www.meharhealthcare.com/bp.html, 2001. Accessed on 7th February 2006.

29. BIPITONE, *Electronic Blood Pressure Meter*, available at: http://www.eeconnet.com. Accessed on 7th February 2006.

30. HEALTH-O-METER, *Blood Pressure Monitors*, available at: http://www.healthometer.com. Accessed on 2nd January 2006.

31. LUMISCOPE, *Digital Blood Pressure Meters*, available at: http://www.lumiscope.net, 2001. Accessed on 3rd January 2006.

32. FORECARE, *Blood Pressure Monitors*, available at: http://www.forecare.com, 2001. Accessed on 5th February 2006.

33. Wikipedia Online Library, *Torr*, available at: http://www.wikipedia.org. Accessed on 2nd March 2006.