Blood pressure monitoring system: real time-continuous and noninvasive-electronic, based on magnetic dipole moment of the proton spin of hydrogen atoms in the blood

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Abstract. This research is motivated by the fact that blood pressure monitoring devices currently available cannot be integrated practically with other electronic health monitoring devices. The research is aimed to obtain a real time-continuous and noninvasive-electronic blood pressure monitoring system with a magnetic coil technique. This technique is a simplified form of the nuclear magnetic resonance (NMR) technique because the induced EMF that is obtained does not involve resonance but rather by sudden population changes and relaxation of the magnetic dipole moments of the proton spin of hydrogen atoms in the blood, both when systole and diastole. The benefit of this research output is that it can obtain noninvasive-electronic blood pressure monitoring devices, and the monitoring process does not interfere with blood flow in the branchial artery samples, so that the monitoring equipment can be integrated with other health monitoring equipment practically. The methodology of this research was carried out by placing a sample arm between two poles of a permanent magnet with a magnitude (7,300 ± 200) gauss and his or her hand inside the receiver coil (involving 2,000 turns), after going through a 500 times voltage gain an induction EMF (in volts) was displayed on digital storage oscilloscope screen. This is done when the sample is relaxed (17 volts is obtained), shortly after jogging (26 volts), and the relaxed state a few moments later (12 volts). The result is that the induced EMF signal enlarges and widens shortly after jogging but slides back when the sample return to relaxed. It was concluded that this blood pressure monitoring equipment of the magnetic-coil technique could be used as a blood pressure monitor.

1. Introduction
Information on the value of blood pressure (BP) in a person is believed to be related to the level of health of that person [1]. The need for information on BP values can be overcome by using BP measurement devices, both invasive (such as catheters) and non-invasive (for example sphygmomanometer (SPY), tonometer, and oscillometric) [2,3,4,5,6]. As for the information needs dynamics of BP can be overcome through the use of blood pressure monitoring equipment (BPME). At present, BPME which is non-invasive is real-time, continuous, and electronic and is needed so that it can be integrated with other health monitoring equipment (HME) [7,8].

The problem, BPME that is commonly used today, is generally non-electronics so it cannot be integrated with other HME (Figure-1). Actually, non-invasive BP measuring devices have been made electronically, for example digital SPY. It’s just that the tool is not practical because it is still not real-time and non-continuous. It is caused, when the device is used, is disrupting blood flow in the branchial arteries of the sample.
This research aims to be able to make and test BPME based on sudden population changes of the magnetic dipole moment of the proton spin of hydrogen atoms (MDMPSHA) in the blood both when systole and diastole occur. This technique is non-invasive, data is recorded continuously, and the result is induction electromotive force (EMF). It is hoped that from this research output can be obtained a BPME with a new technique that is prospectively integrated with other computerized HME. Furthermore, this BPME is called a blood pressure monitoring equipment with the magnetic coil system (BPME-MCS) technique.

This research is a continuation of a number of stages of previous research. The first stage, it starts with the involvement of MDMPSHA excitation by the radiation of electromagnetic waves (EMW) in the radio frequency (RF) region of the NMR system, so that equality between the induced EMF (by BPME-MCS) and the blood pressure value (by SPY) is obtained [10,11,12]. As a result, the background signal is too strong so that the induced EMF becomes difficult to observe [13,14,15,16]. In the second stage, this BPME-MCS technique does not involve RF but based on sudden population changes of MDMPSHA on the magnetic field strength of about 1,500 gauss, involving 15 samples, and the resulting induced EMF is measured with a voltmeter. As a result, the signal amplitude is still weak (0 – 18 mV) so that it is insensitive [17]. The third stage, the steps carried out as in the second stage, but the magnetic field strength of about 7,200 gauss, involving 50 samples, and each sample of data obtained by photographing the induced EMF signal on the digital storage oscilloscope (DSO) screen. As a result, a signal that is more sensitive to 70% reproducibility is obtained, but it is not real-time and is also not continuous [18].

This BPME-MCS does not interfere with blood flow in the branchial arteries, but the presence of systole – diastole can be known from the relaxation of MDMPSHA (\(\vec{\mu}\)) in the blood flowing in the arteries. Before entering the area with \(\vec{B}_b\) magnetic field (Figure-2), the MDMPSHA are directed randomly. But when the MDMPSHA are between the two magnetic poles (north or N and south or S) then the orientation of the MDMPSHA is separated into three orientations. The third orientation is the lowest energy (\(E_a\)) with population \(N_a\), the highest energy (\(E_b\)) with population \(N_b\), and the third energy (\(E_c = 0\)) with a population \(N_c\). In the third orientation, the MDMPSHA are not affected by the magnetic field \(\vec{B}_a\), because of the angle between \(\vec{\mu}\) and \(\vec{B}_a\) is 90°.
Figure 2. The schematic change in MDMPSHA orientation by systole and diastole which causes induction EMF.

If the MDMPSHA population before entering the magnetic field space is \( N_0 \), then that population can be associated with the MDMPSHA population when in the magnetic field space \( B_0 \), namely:

\[
N_0 = N_a + N_b + N_c
\]  

MDMPSHA (\( \mu \)) energy in magnetic field (\( B_0 \)) space is \( E = -\mu \cdot B_0 \) which means that if the angle formed between \( \mu \) and \( B_0 \) is \( \theta \), so \( E = -\mu B_0 \cos \theta \). That is, the lowest energy occurs when the angle of \( \mu \) is equal to \( B_0 \) so that \( \theta = 0 \), \( E = E_a = -\mu B_0 \). The highest energy occurs when \( \mu \) in the opposite direction with \( B_0 \) or \( \theta = \pi \) so \( E = E_b = +\mu B_0 \), whereas when \( \mu \) perpendicular to \( B_0 \) then \( E_c = 0 \). Furthermore, the MDMPSHA population in the three orientations in the magnetic field follows the Boltzman distribution. Based on equation 1, the total population of MDMPSHA is \( N_0 \) which occurs at temperature \( T \) and Boltzman constant \( k \), so the population of MDMPSHA at energy level \( i = (E_i, i = a, b, c) \) is \( N_i = N_0 e^{-\frac{E_i}{2kT}} \). That means the MDMPSHA population in the low energy is

\[
N_a = N_0 e^{\frac{\mu B_0}{2kT}}
\]  

Whereas the upper energy is

\[
N_b = N_0 e^{-\frac{\mu B_0}{2kT}}
\]

As for the results of the comparison between the two populations is

\[
\frac{N_a}{N_b} = e^{\frac{\mu B_0}{kT}}
\]

Equation 3 shows that \( \frac{N_a}{N_b} > 1 \), and the results of the comparison can be enlarged by increasing \( B_0 \) and or decreasing \( T \). But in this case, \( T \) is the temperature of the MDMPSHA in the blood so that it matches the body temperature of the sample. That is, in this research \( T \) cannot be regulated and only \( B_0 \) can be regulated. If \( B_0 \) is large, then \( N_a \gg N_b \) and that causes the resulting induced EMF to be even greater.
Of course, the value of $N_a$ also depends on the value of $N_o$. When systole and diastole occur, the $N_o$ number becomes large and it results in the $N_a$ becoming larger even if only for a short time, and that is the event that causes the resulting induced EMF to become larger.

2. Material and experimental method

This research uses the material in the form of blood flowing in the brachial artery of the sample. In the blood contains MDMPSHA. Based on the dynamics of the MDMPSHA population in the blood interacting with the static magnetic field, an induced EMF can be obtained.

As for the equipment from BPME-MCS, it consists of three components, namely: main, supporting, and comparison components. The main components (homemade) include permanent magnets inside the table (about 7,200 gausses in strength) and a receiving coil (RC) which involves 2,000 turns of 0.1 mm diameter wire (Figure-3). Supporting component in the form of filter-amplifier and DSO. As for the comparative component in the form of a digital SPY DU-150 that has been calibrated.

![Figure 3. Portrait: (a) RC, and the permanent magnet is seen from above (b), seen from the front (c).](image)

The existence of the BPME-MCS chart is shown in Figure-4. The process of monitoring BP with this technique is done by placing the sample arm between the two magnetic poles (N and S) while the sample hand is on the RC axis. Chosen RC length is 7 cm and distance RC to the end of the magnetic pole nearest is 3 cm. The selection was based on the time of transversal relaxation of MDMPSHA in blood ($T_2$) was 0.2 s, while the speed of blood flow (in the branchial artery which was 0.5 cm in diameter) was about 0.5 m/s. Therefore, at that time interval MDMPSHA relaxes and when it travels a distance of about 10 cm.

![Figure 4. BPME scheme with the MCS technique and how to use it.](image)
The presence of systole, diastole, and static magnetic fields causes sudden changes in the MDMPSHA population in arteries branchial and also that relaxation. This causes the RC to give the output in the form of an induction EMF. The RC output is connected to the filter (20 Hz)-amplifier (500 times, in volts) and the results are displayed on the DSO screen, and the results continuous signals that can be stored on a flash disk.

Data collection was carried out on samples that were relaxing and shortly after the sample jogged. Monitoring is carried out in two steps, namely: non-continuous, and continuous. Step-1, BP on the two arms of the sample are measured simultaneously, the right arm with BPME-MCS while the left arm with SPY. Furthermore, the dynamics of induction EMF values are obtained which are proportional to the results of SPY readings. Step-2, just the right arm whose BP is monitored with BPME-MCS both regarding systole and diastole so as to obtain a continuous and real-time induced EMF signal and the results are displayed on the DSO screen.

3. Experimental result
The results of the experiment step-1 are shown in Figure-5. These results show that the value read by BPME-MCS (induction EMF, in volts) is proportional to the real value in SPY both when the sample is relaxed or shortly after the sample jogs (for 5 minutes). These results indicate that physical activity (jogging) is to increase the value of BP. Just that, the quantitative information is obtained separately by a number of data points, each data were taken every 5 minutes and the resulting signal is not continuous.

![Figure 5. The dynamics of BP samples that are monitored with BPEM-MCS and SPY simultaneously involving the effect of the physical activity of the sample.](image-url)
Step 2 gives information on the pattern of the induced EMF when the sample is: relaxed (figure 6a), shortly after jogging (figure 6b), and five minutes after jogging is finished (figure 6c). The two signals from each of these appearances are shown successively in Figure-7a,b,c. These results show that the signal produced is really related to the BP value of the sample. This is evidenced by the low signal height when the sample is relaxed (after being amplified 500 times giving an induction EMF around 17 volts), shortly after the sample jogs (for 5 minutes) giving an induction EMF around 26 volts. Then the signal drops to 12 volts after the sample has rested for 5 minutes from the end of jogging. In addition, the higher EMF signal gives the wider on the signal pattern. This proves that the relaxation of the MDMPSHA makes the widening.

![Figure 6](image1.png)

**Figure 6.** Induction EMF signal pattern recorded by DSO when the sample is in a state: (a) relaxed, (b) shortly after jogging, and (c) five minutes after jogging.

![Figure 7](image2.png)

**Figure 7.** Two signals from the induction EMF pattern recorded by DSO in a state: (a) relaxed, (b) immediately after jogging, and (c) after five minutes of jogging.

4. **Discussion**

The experiment results as shown in Figure-5,6 prove that the homemade BPME-MCS can be used prospectively as a real-time and continuous BP monitor. Other than that, BPME-MCS is practical and electronic, the nature of which is shown in Figure-8. Called practical because the technique is principled pulse BP so that it does not interfere with blood flow in the branchial arteries. Called electronics because
of sudden population changes of MDMPSHA by systole ($N_{01}$), diastole ($N_{02}$), and relaxation (time interval $T_2$) gives an output in the form of an induced EMF from RC. This condition causes BPME-MCS can be integrated with other HME, and the results of its monitoring can be displayed on a computer screen.

An induced EMF signal (figure 6,7) actually contains a pair of signals when an appropriate time base is used (figure 9). In that pair of signals, the highest signal is related to systole and the other signal is related to diastole. The existence of a pair of signals can be linked to a BP diagram in the medical language. In that pair of signals, the highest signal corresponds to systole in both physical and medical languages. Meanwhile, the peak point of diastole (physics) corresponds to the turning point of diastole (medical). This is caused by the (medical) BP pattern of diastole which is immediately followed by systole at the next pulse (figure 10).

![Figure 8. Schematic dynamics of MDMPSHA in the blood by the influence of magnetic fields that are associated with practical and electronic of BPME-MCS.](image1)

![Figure 9. Systole-diastole pattern on the induced EMF signal.](image2)
5. Conclusion
BPME-MCS has been successfully obtained with the results of monitoring in real-time, continuous, practical, and electronic so that perspective can be integrated with other health monitoring devices (electronic). Hopefully this BPME-MCS is not BP gauge but its existence is closely related to BP measuring devices. Therefore, the presence of BPME can be used to determine the dynamic of BP in a person.

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