Analysis of a GMR-Based Plethysmograph transducer and its Utility for Real-time Blood Pressure Measurement

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***Abstract*— The paper presents study and analysis of a Giant Magneto Resistance (GMR)-based magneto plethysmograph and illustrates its efficacy as a tool for real-time cuff-less measurement of Blood Pressure (BP). The proposed scheme employs two GMR sensors and associated biasing and signal conditioning in its architecture. The delay between output of the GMR sensors is used to estimate the BP. The methodology, circuits and signal processing stages used are described in the paper. A prototype of the GMR-sensing solution is developed and tested. Initially, tests are carried out to determine the quality and characteristics of the plethysmographs produced by developed sensor unit, in different conditions such as various body positions, bias current etc. Good quality bio-signals were obtained during the above tests. Then, the experiments were conducted on 29 volunteers to find the feasibility of developed scheme as a BP monitor. The results obtained show that the performance of developed BP monitor is within acceptable limits.**

Keywords— Blood Pressure, Pulse Transition Time, Pulse Wave Velocity, Real time Blood Pressure measurement, Non-Invasive Blood Pressure measurement.

I. INTRODUCTION

The most important parameters for primary health diagnosis include Respiration Rate (RR), Heart Rate (HR) and Blood Pressure [1,2,3]. Non-invasive devices capable of measuring above health parameters have gained considerable importance in the recent years. Desirable features for such bio-instruments include compactness and low-cost, good accuracy and sensitivity, low power operation, capability for real-time operation, low amount of calibration, etc. In this paper, we analyze the performance of a magneto-plethysmograph and investigate its application for real-time blood pressure measurement. The magneto-plethysmograph is based on giant magneto resistance principle and the overall sensing solution is shown to possess the aforementioned desired features of a bio-instrument.

Different methods [4] are reported for monitoring of HR, RR and BP. Many of these techniques are particular for single body parameter, while some others could be used as a universal solution. Out of these parameters, BP is the most important tool for diagnosis of cardiovascular diseases [5]. Commonly used devices for BP measurement are Mercury Sphygmomanometer, Aneroid and Oscillometric devices. Mercury Sphygmomanometer is considered the benchmark for office assessment of BP [6]. Mercury Sphygmomanometer technique possesses a constant threat of mercury spills. The accuracy of Aneroid sphygmomanometer is well established, however this device requires greater maintenance and more frequent calibrations [7]. Oscillometric Sphygmomanometer is an automated device and does not require observer participation for BP measurement [8]. The above methods are cuff based methods. They are accurate, however may cause discomfort to the examinee. These methods are also not suitable for continuous BP monitoring.

Pulse Wave Velocity (PWV) is defined as velocity of arterial pulse through cardiovascular system and can be used as a good estimator of BP [9,10]. Based on PWV and BP correlation, cuff-less solutions for BP estimation using Phonocardiogram and Photoplethysmograph techniques have been developed [11]. In this work we develop a GMR sensor system for PWV and BP measurement. The proposed system does not require the use of cardiogram signals and associated signal processing stages to estimate PWV. GMR sensor can provide Magneto Plethysmographic (MPG) signal equivalent to disturbance caused by arterial blood flow in magnetic field. The similar GMR sensing modality can be used for HR [12], RR [13] measurement. The system shown in Fig. 1 gives good MPG signals at different positions along the arm length. The dual GMR sensor configuration is used. GMR sensor outputs from different radial artery positions are similar, but differ in phase. This phase difference information is then utilised for estimation of Pulse Transition Time (PTT) [14]. PWV can be calculated as a division of distance between signal acquisition

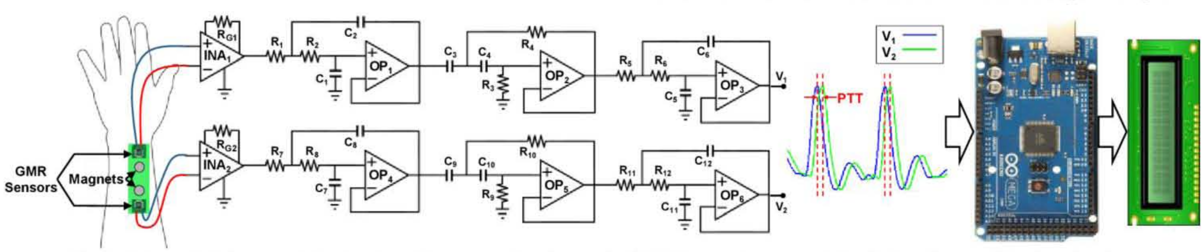


Fig. 1. Schematic Diagram of the developed Prototype showing typical PTT for a volunteer and detailed analog conditioning circuit.

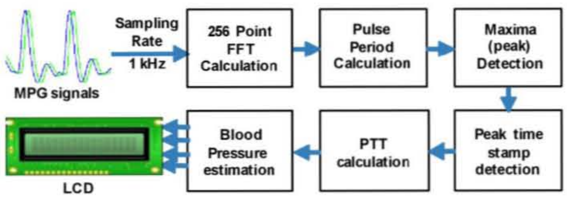


Fig. 2. Block diagram of Blood Pressure estimation algorithm.

sites by PTT. Such system would be efficient in real time measurement of PWV in non- invasive manner and would be free from setbacks of cuff based methods. Viability of the proposed method is established by building a prototype and testing on 29 volunteers. Detailed working of the proposed system is described in the next section. Section (III) deals with Experimental set-up and Results obtained and section (IV) provides the concluding remarks to the experimentation and references.

II. MEASUREMENT METHODOLOGY

The prepared GMR based system comprise three main parts (a) Signal acquisition stage, (b) Analog front-end, and (c) Digital back-end. These parts are explained in following sub-sections.

A. Signal Acquisition stage

A GMR sensor when biased properly can generate a differential signal analogous to the minute changes in surrounding magnetic field. This technique can be utilised to get MPG signal corresponding to volumetric changes made in blood flow due to cardiac activity. In our experimentation, we have used two GMR sensors AA002-02 [15] from NVE Corporation. Two permanent magnets (Amazing Magnets – D063D-N35) are used to bias the GMR sensors in the linear region of operation. The sensors are placed 9 cm apart on a non-magnetic base at radial artery position as can be seen in Fig. 3. The two MPG signals thus observed have an inherent phase difference due to time taken by the pulse to reach from one measurement site to another. The separation between sensors also ensures that the biasing magnetic field of one sensor doesn't affect the other. These differential signals are then conditioned using analog front-end as described below.

B. Analog front-end

The differential outputs of the MPG sensors are amplified using Instrumentation Amplifier (INA129) with gain of 800. Thus obtained single ended amplified signals are passed through second order sallen key low-pass filter with cutoff frequency 10Hz to suppress higher frequency noises and power line interference. These filtered signals contain both HR and RR components. To remove RR component, we use second order sallen key high-pass filter with cutoff frequency 0.7 Hz. Another second order low-pass filter was used to further reduce high frequency noises. The filters were designed using op-amp OP07 from Texas Instruments. The conditioned signals thus obtained are shifted to 0-5V and are forwarded to digital back-end for PWV computation.

C. Digital back-end

The analog signals (having primary frequency component 1-2 Hz) are sampled at sampling frequency 1 kHz. 256 point FFT is implemented on one of the MPG signals to find the heart rate and so the pulse period of volunteer. Peaks are detected by maxima detection in every consecutive pulse period and the time stamps of occurrence of corresponding peaks are recorded. PTT is calculated as the difference of peak time stamps of two MPG signals. PTT varies from beat to beat so an average is taken over 5 pulse periods to obtain a stable PTT. PTT values have a quantization error of 0.5 msec. For our experimentation the distance between two measurement sites is fixed so PTT is an indirect measure of PWV. For estimation of Blood Pressure from PTT we use the equation

$$BP = P + \frac{Q}{PTT}$$

where P and Q are constants estimated using linear regression over previously obtained data. Simplified Block diagram of Peak detection algorithm is shown in Fig. 2. The results have been discussed in following section.

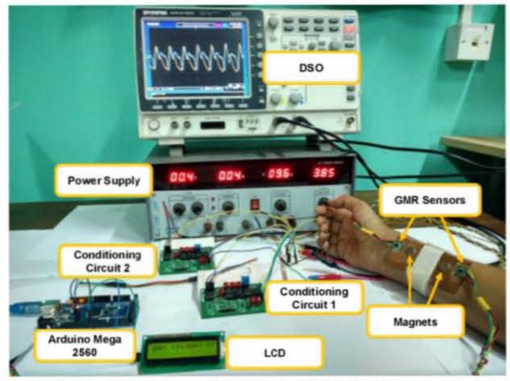


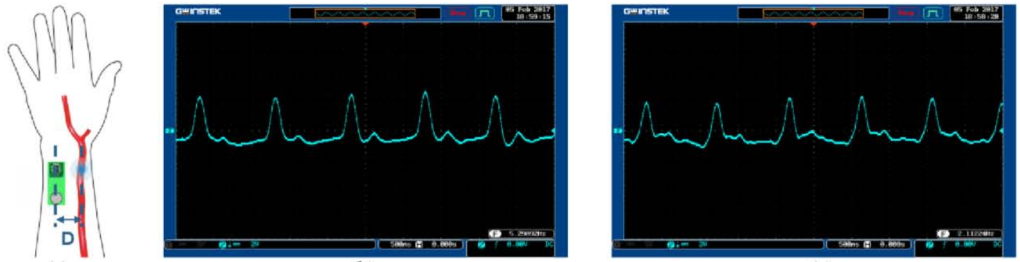
Fig. 3. Experimental setup for real time blood pressure estimation.

III. EXPERIMENTAL SET-UP AND RESULTS

The developed experimental prototype is shown in Fig. 3. GMR sensors and biasing magnets combined are used for signal acquisition. Conditioning circuits 1 and 2 are used for analog domain signal processing of two MPG signals. Typical MPG waveforms are displayed on oscilloscope (GDS-2102A from GW Instek). Arduino Mega 2560 is used for digital domain processing and algorithmic implementation. LCD is used to display estimated blood pressure in real time. Tests are conducted on the developed prototype. These tests include (1) performance study of GMR plethysmograph when placed at different positions, (2) effect of bias current variation on plethysmograph performance and (3) efficacy study of GMR based BP monitor.

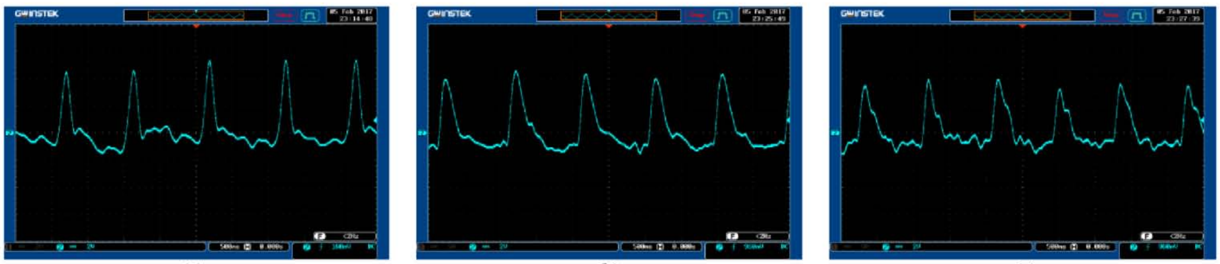
A. Performance of developed plethysmograph at different body locations

The GMR-based plethysmographs are known to give good quality signals when the sensor unit is placed at radial artery position. Here, we study the quality of GMR signals at different body locations. In this test the relative position of GMR IC and magnet were fixed over a non-magnetic plate. The plate was gradually displaced in perpendicular direction to the radial artery as shown in Fig. 4(a). The observations are recorded in Table 1 with related waveforms in Fig. 4(b) and Fig. 4(c). It can be observed that the placement of sensor on



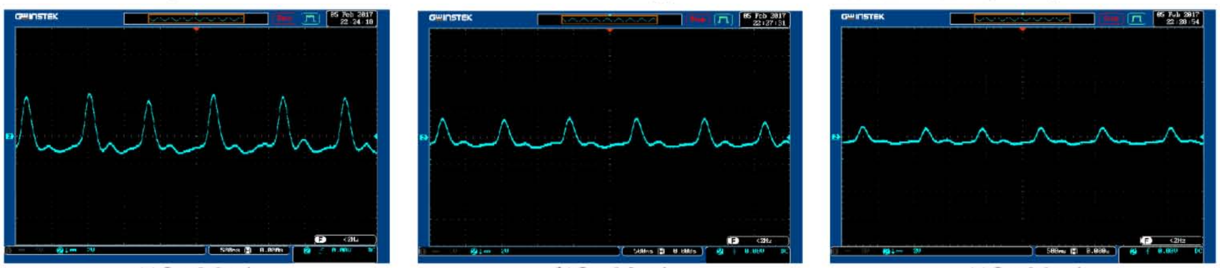
(a) (b) (c)

Fig. 4. Displacement (D) of sensor unit w.r.t. radial artery is shown in (a). MPG signals observed at D = 0 mm and D = 25 mm are shown in (b) and (c).



(a) (b) (c)

Fig. 5. MPG waveforms observed at Wrist, Lower Arm, and Upper Arm are shown in (a), (b) and (c) respectively.



(a) $I_b = 0.6$ mA (b) $I_b = 0.3$ mA (c) $I_b = 0.1$ mA

Fig. 6. MPG waveforms observed for a volunteer at three different biasing current (I_b).

different wrist positions was giving similar results. The observation can be supported by presence of Brachial and Radial artery across wrist. These observations prompted a similar sensor displacement study along arm, the corresponding waveforms are shown in Fig. 5. The waveforms observed at wrist, lower-arm and upper-arm have similar signal strength. It can be inferred from above study that the GMR sensor can provide good quality MPG signal even at positions where arteries are a bit distant from surface of body.

TABLE I. DISPLACEMENT STUDY ACROSS WRIST

Displacement (mm)	0	1	2	4	11	15	19	25
Signal Strength (V)	3.8	3.5	3.6	3.5	3.4	3.5	3.8	3.6

B. *Effect of bias current on sensor unit*

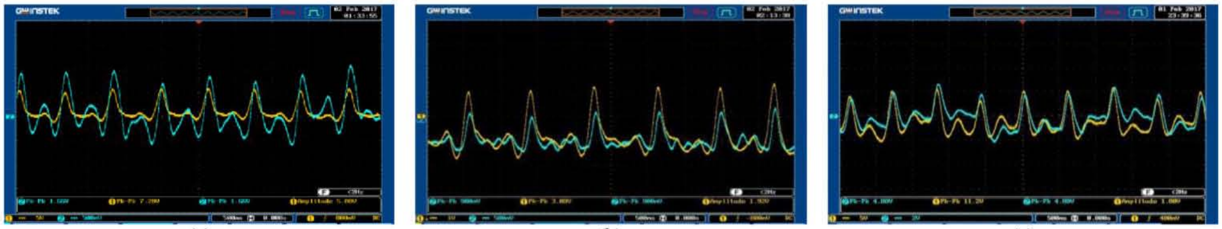
With keeping in mind the low power implementation for building a compact prototype, the effect of different bias currents on GMR sensor performance was studied. The supply current to GMR IC was provided through a simple current mirror circuit. Potentiometer was used in current mirror to generate a variable current source. Bias current was measured using multimeter (Fluke 87V) in series with current mirror. The plethysmographic signals were recorded for current as low as 27μA. The observed readings are reported in Table 2 with corresponding waveforms in Fig. 6. It can be inferred from Fig. 6 that the GMR sensor used at low biasing currents can also give quality output and hence is a fit transducer for development of low power health monitoring system.

TABLE II. BIAS CURRENT STUDY

Bias Current (mA)	0.9	0.6	0.4	0.3	0.2	0.1	0.05	0.027
Signal Strength (V)	6.6	4.4	3.2	2.0	1.3	0.64	0.34	0.14
SNR (in dB)	83	66	58	55	53	52	51	49

C. *Efficacy study of GMR based BP monitor*

The feasibility of developed prototype (having 2 GMR sensors) for BP estimation was tested for 29 volunteers. Typical MPG waveforms obtained at two measurement sites are shown in Fig. 7 for 3 out of the 29 volunteers who participated in the experiments. Systolic (SBP) and Diastolic (DBP) BP were recorded using Omron HEM-7120 as a reference monitor [16]. PWV is measured by application of Peak detection algorithm using developed prototype. Mean arterial pressure (MAP) for a volunteer was calculated as an average of SBP and DBP. PWV was plotted against SBP, DBP and MAP and a best linear fit for the data was obtained as can be seen in Fig. 8, 9 and 10. The correlation coefficient (r) for PWV and BP was observed to be 0.61 for SBP, 0.70 for DBP and 0.74 for MAP. Thus the developed prototype can be used for cuff-less estimation of Blood Pressure.



(a) (b) (c)

Fig. 7. MPG signals showing Pulse Transition Time for three different volunteers.

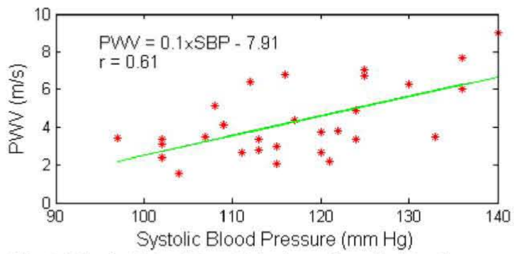


Fig. 8. Plot for Pulse Wave Velocity vs Systolic blood pressure.

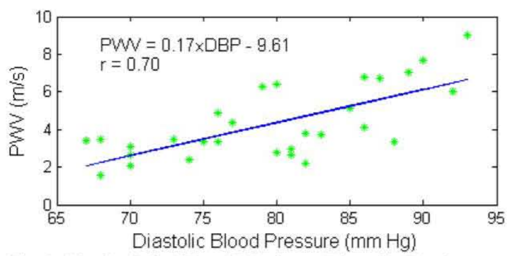


Fig. 9. Plot for Pulse Wave Velocity vs Diastolic blood pressure.

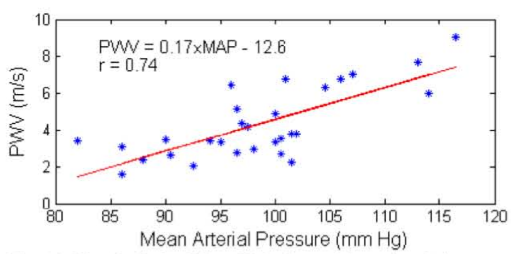


Fig. 10. Plot for Pulse Wave Velocity vs Mean Arterial pressure.

IV. CONCLUSION

A non-invasive cuff-less measurement scheme for estimating PWV and BP was presented in this paper. The scheme uses a twin GMR-sensor configuration as the basic sensing element. The scheme does not require cardiogram signals opposed to most of existing cuff-less BP measurement modalities. The outputs were processed using analog front-end to obtain stable plethysmograph signals. The ability of the plethysmograph to produce good quality bio signals were illustrated using experimentation on developed prototype. Later, these signals were processed using simple, but efficient peak detection algorithm and moving window approach to obtain delay between the sensor outputs as well as PWV and BP. The performance of the developed BP monitor was tested on volunteer trials (29 volunteers). The correlation coefficient was observed to be 0.61 for SBP, 0.70 for DBP and 0.74 for MAP. Worst case error for MAP estimation was observed to be ±9 mm Hg (Fig. 10). As a potential direction of low power optimization of system, bias current study was done on sensor. This study reflected that the design can provide significant output for extremely low bias currents. Thus the proposed system could be used to develop a low power, real-time, cuff-less solution for rugged measurement of BP. P and Q parameters are estimated using linear regression on pre obtained data points, hence per patient calibration is required for BP estimation using proposed modality. Detailed study on medium and long term stability of these parameters is the future exent of this work.

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