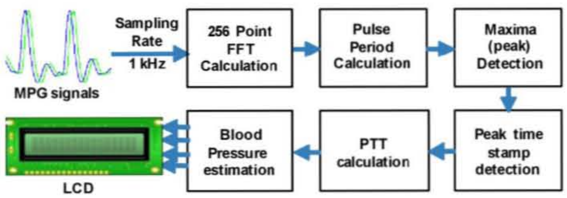

Fig. 2. Block diagram of Blood Pressure estimation algorithm.

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.

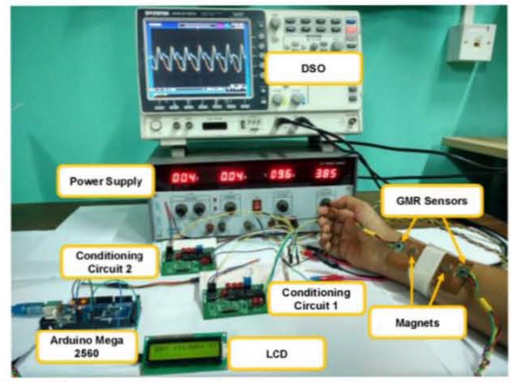

Fig. 3. Experimental setup for real time blood pressure estimation.

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