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Mobile Application: ECG Signal Processing for Deviation Detection of Heart Rate Variability (HRV)

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Abstract: *Flexible electronics based ECG electrode patches are under evolution, to comfort the Cardiovascular Disease (CVD) patients, whose condition has to be monitored on-line on continuous basis, even during sleep. Body area electronics has preliminary signal processing at the front end in analog domain, eliminating some of the electron conduction based noise, from the Ion conduction based Electro Cardio Gram (ECG) potentials originated from cardiac anatomy. Rest of the preprocessing in the digital domain and deviation detection of ECG is done on system side and in this approach on Mobile side. There is specific advantage in using a Mobile phone as a central ECG acquisition system, both for individuals, as well as ICU or doctor's station, in the house and hospital environment respectively, as a separate display screen required for ECG diagnostic results is avoided. In order to utilize Mobile as Digital Signal Processing (DSP) device and also medical device display screen, a microprocessor based hardware module with embedded mobile communication is evolved, to introduce between the front end ECG Sensor patch of body area electronics and the USB or Near Field Communication (NFC) port of the mobile. In fact, Mobile's USB or Near Field Communication (NFC) port, in addition to acquiring Digitized ECG data, need to power the Body area electronics. An end to end ECG deviation detection methodology evolved for Mobile Application is illustrated, for Heart Rate Variability (HRV) based on the deviation detected in the R to R interval of the QRS complex of the ECG.*
Keywords: *Near Field Communication (NFC), ECG electrode, Electro Cardio Gram, Body Area Electronics, QRS Complex*

I. Introduction

Heart attack and Stroke cause a big burden on society, due to their high cost of care, lower quality of life and premature death, specifically when not detected early. There has been a requirement of Mobile application with USB or Near Field Communication (NFC) dongle and Flexible electronics ECG patch electrode, for on line continuous ECG acquisition, whenever required, to detect deviation of ECG, if any, for home care as well as hospital and ICU care. Compared with monitoring at hospital premises, home based tele-monitoring not only provides, financial advantage and gives patient freedom of staying at home and normal quality life, with connectivity to hospital [1]. Sensing Bio-potential signals with flexible epidermal patches is a felt need among clinicians and neuroscientists with integrated circuits capable of amplifying bio-signals in the mHz to kHz range, while rejecting large DC offset generated at the electrode-tissue interface. Bio-potentials in general are very week in the range of a few µV to mV, which necessitate high fidelity and low power consumption, in these designs [16]. ECG is one such Bio-potential signal, which gives advantage in diagnostics, when monitored on-line in CVD patients.

II. ECG R-R Interval Detection

ECG usage has been widely employed, to diagnose different heart abnormalities, detecting ECG deviations. The research of real time R-R peak detection on Mobile phone is the foundation step for all the future research of Mobile phone based, ECG deviation monitoring, from real time acquired ECG recordings. Different patterns of a normal ECG graph are denoted by P, Q, R, S and T as indicated in the Fig 1, below and it is a non stationary waveform, on which wavelet transforms are used for analysis rather than fourier transforms, for resolutions both in frequency and time domain.

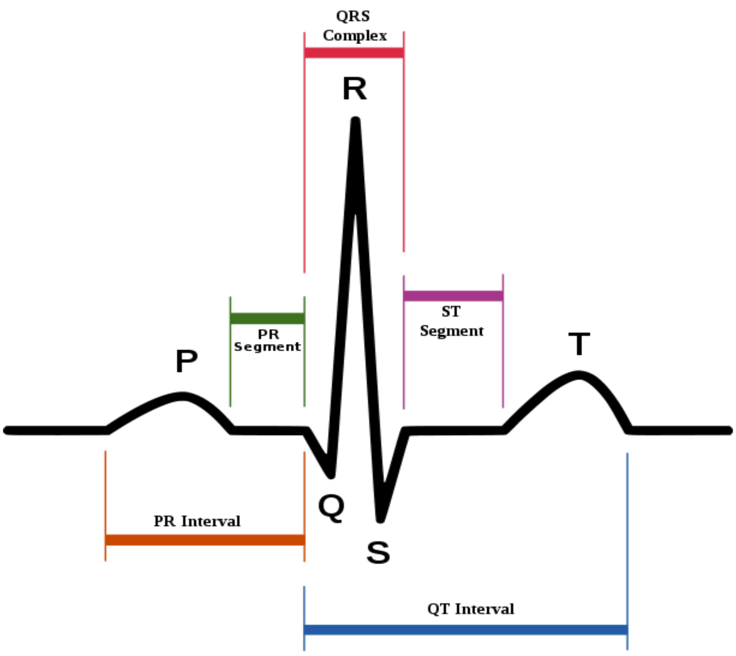

Fig 1

Since, wide range of heart diseases like Tachycardia, Bradycardia, Arythmia, Ishchemea etc are efficiently diagnosed utilizing the detected R – R interval, relevant R – R deviation algorithm is evovled. Practical results indicate, even primitive Mobile phones, do possess the computation power required for algorithms, to detect R – R peak interval in real time. Using R – R interval computed, acquiring digitized ECG on-line, via. Mobile phones at regular time stamped intervals, Heart Rate Variability (HRV) is computed, time stamping the values. A graph is plotted using these HRV values on the Y-axis and time intervals on X-axis. The high frequency part (1.8 – 4 Hz) of HRV corresponds to respiration and the low frequency part (0.4 – 1.5 Hz) is related to vagus and cardiac sympathetic nerves. In the past, there has been reported correlation of reduced Heart Rate Variability (HRV) and the patient death. The Algorithm for R – R deviation detection and charting Heart Rate Variability (HRV) evolved is illustrated below, for applying subsequent to preprocessing ECG for noise, vander etc. Also in earlier publication [7] ECG waveform is segmented in to 410 Cubic Splines for wavelet transform analysis for deviation detection on systems.

ALGORITHMIC sequence for R- R interval deviation detection:

DIGITIZE ECG ( ) ;

RETURN ($X_i = X_1, X_2,$ -------------------------, X_i) $\longrightarrow$ (1)
Where i = 1,2,3,----------------,i is the length of the digitized signal with a sampling i_r

QRS COMPLEX_CANDIDATE_SETS_OF_ECG ($X_1, X_2,$ ------------------------, X_i);

RETURN (X_r, X_{r+1}, X_{r+2}, ------------------------, X_{r+k}), --------------------------------
------------------------, (X_l, X_{l+1}, X_{l+2}, ----------------------------------, X_{N-C}) > Threshold Value

$\longrightarrow$ (2)
Where 1 < r < l < N and X_{N-C} is the last value greater than the threshold and both X_{r+k+1} and X_{n-c+1} are less than the amplitude threshold.

DETECT_QRS_PEAK_IN_EACH_WINDOW Δ_W _ 660 ms < Δ_W < 1500 ms ( );

RETURN (R_P Peak = Max value of R (within a Δ_w) $\longrightarrow$ (3)
Where P = No of Beats

DETECT AVERAGE $R_{PEAK} – R_{PEAK}$ INTERVAL ( );

RETURN (AVERAGE INTERVAL);

RETURN ($R_{AVERAGE\ INTERVAL}$ = R1 + R2 + R3 ---------------R_P/ P);

COMPUTE HEART RATE VARIABILITY_AT_A_TIME STAMP ( );

RETURN (1/(R1 $_{AVERAGE\ INTERVAL}$ - R2 $_{AVERAGE\ INTERVAL}$ /Time), Time Stamp);

CHART HEART RATE VARIABILITY( );

RETURN (DISPLAY HRV vs TIME GRAPH);

If Hear Rate Variability (HRV) is high, Tachycardia is diagnosed and if low HRV, patients are diagnosed as Bradycardia patients.

III. Flexible ECG Electrode Sensor

A gel free non contact [8] ECG sensor design that couples capacitively with skin [8] need to have a front end low noise TFT current mirror based differential amplifier, to make it work with the low power derived from Near Field Communication (NFC) RF source or USB port of the Mobile phone, autonomously as an epidermal device. Design exercise undertaken, earlier [4] is given below in Fig 2, which is used in the scheme of the present Mobile application for ECG processing. Designed values published [4] are given below in Table 1 below

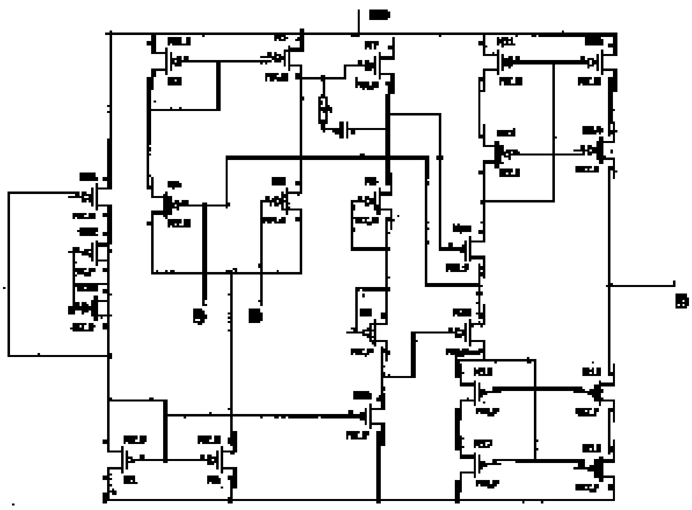

Fig 2 (ECG Flexible Amplifier)

M1, M6,M10,M17,M18	1500/25µm
M2,M3,M19	3600/25µm
M8,M9	7200/25µm
M11,M12	750/25µm
M13,M14	1100/25µm
M15,M16	2200/25µm
M22,M23	600/25µm
M21	3000/25µm
R,C	1KΩ, 33pf

Table 1: Designed W/L ratios of Thin Film Transistors, R and C values of Flexible ECG amplifier

IV. Hardware Scheme For USB Or Near Field Communication(NFC) Of Mobile Phone With Body Area Electronics

A hardware dongle is required to be connected to Mobile phone, in order to acquire digitized analog ECG from Flexible body area electronics. Block diagram of the hardware design is indicated below in Fig 3. Embedding codified algorithm for Digitization of Analog ECG from Flexible ECG sensor for sending data via. Near Field Communication (NFC) /USB , for R-R deviation or interval detection of QRS complex of ECG, to windows Mobile phone illustrated above in section II, is using the available Integrated Development Environment (IDE) µ Vision 5.0, for compiling and linking to generate binary image and to convert into HEX file for burning the PROM of the processor. The generated HEX file is downloaded using Magic Flash software tool and it's Microprocessor 's PROM burning board with ZIF socket. The windows mobile has to be 4G technology with Near Field Communication (NFC)/USB communication capabilities

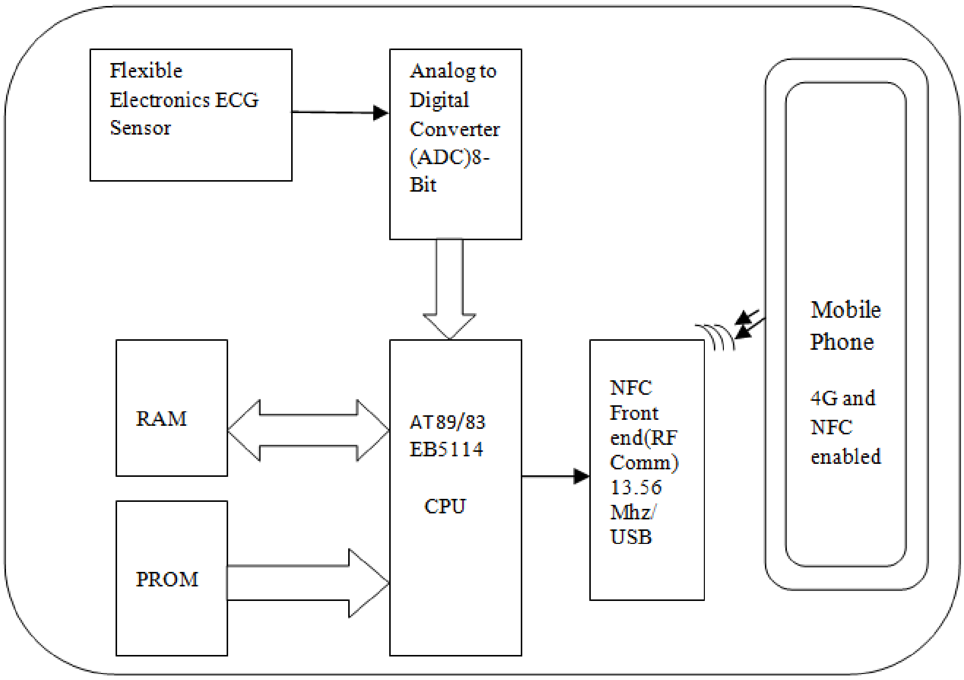

Fig 3 Block Diagram of Body Area Electronics Dongle for Mobile Phone Communication

V. ECG Dongle Communication With Mobile Using Near Field Communication (Nfc) Protocols

These protocols implemented for Near Field Communication (NFC) with Mobile phone are downloaded to Body Area Electronics processor, using the tools, illustrated in the section III.

NFC Interface and Protocol:
Protocol Flow Top View:

- ECG dongle NFC device shall be kept in Target mode initially and not generate an RF field and shall wait for a command from an Initiator mobile phone
- Mobile Phone's NFC device shall be in Initiator mode and select passive communication mode
- Mobile Phone's NFC Initiator device shall test for external RF field presence and shall not activate their RF field, if an external RF field is detected
- If an external RF field is not detected, the Mobile NFC device shall activate its own RF field for the activation of target ECG dongle device
- Exchange commands and data responses between Mobile Phone and ECG dongle with the decided communication mode using transport data frames

Initial RF Collision Avoidance:

- To initiate communication with the target device either in the active or the passive communication mode, a Mobile initiator device shall sense continuously for the presence of an external RF field.
- If no RF field is detected by the initiator, within the time frame $T_{\text{initial delay time(IDT)}} + n \times T_{\text{RF waiting time(RFW)}}$, then the initiator shall 'switch on', it's RF energy, else initiator shall restart Initial RF Collision Avoidance, where $T_{IDT} > 4096/f_c$, $T_{RFW} = 512/f_c$ and $f_c = 13.56$ Mhz, 'n' is randomly generated number between 0 and 3
- Initial guard time between switching an RF field and start to send command or data frame, $T_{\text{Initial RF guard}} > 5$ ms is maintained in the transmissions

Response RF Collision Avoidance:

- Collision due to simultaneous response by more than one Target in the active communication mode, during activation, ECG devices send response, after a time of

T_{ADT} + n x T_{RFW} + T_{ARFG} , where 768 / f_c <= T_{ADT} <= 2559/f_c

T_{RFW} = 512/f_c, 'n' – Random Generated number between 0 and 3

$T_{Active\ RF\ Guard\ Time}$ > 1024/f_c

Passive communication mode of ecg device:
ECG dongle Initialization and Single Device Detection (SDD) is by sending hex 'DA' in the following frame format shown in Fig 4 below, as a response to the Mobile Phone NFC Initiator

PREAMBLE = 48 Zeros	**SYNC = 'B24D'**	**LENGTH = 01**	**ECG DONGLE ID = 'DA'**	**CYCLIC REDUNDANCY CHECK (CRC)**

Fig 4. Frame Format

TRANSPORT OF ECG DIGITAL DATA
The ECG Digitized data of size 2 Kbit/sec using the following Transport Frame Format shown below in Fig 5 as specified in ISO/IEC 14443-3

START BYTE = 'F0'	**LENGTH = 255**	**CMD 1**	**CMD2**	**X_1**	**X_2**	------	-------	**X_N**	**CRC**

Fig 5. Frame Format for Transportation and Exchange of Data

Where

CMD1	CMD2	Definition
'D4'	'06'	Data Exchange Protocol Request (Sent by Mobile Phone Initiator NFC)
'D5'	'07'	Date Exchange Protocol Response (Sent by ECG NFC Device)
'D4'	'08'	Deselect Request (Sent by Mobile Phone Initiator NFC)
'D5'	'09'	Deselect Response (Sent by ECG NFC Device)
'D4'	'0A'	Release Request (Sent by Mobile Phone Initiator NFC)
'D5'	'0B'	Release Response (Sent by ECG NFC Device)

The Cyclic Redundancy Check (CRC) is calculated by the following polynomial with a present value of 6363

Polynomial G (X) = $X^{16} + X^{12} + X^5 + 1$. At the end of the calculation presented without inversion

ECG dongle NFC device, which work in Single Device Detection (SDD) mode, communicate ECG data against Data Exchange Protocol Request of the Mobile NFC Device and Responds with ECG Digitized sample's data frame, in it's Data Exchange Protocol Response.

VI. Conclusion

The present algorithm is for detecting ECG deviation for diagnosing Tachycardia and Bradycarida and is extendable to first derivatives and second derivatives of the QRS complex depending on Heart Rate Variability's (HRV) accuracy required for further diagnosis, on Mobile based systems. NFC communication indicated at present is passive mode communication in the above algorithms and further extendable to active mode, depending on requirement of other ECG Diagnostics. As the research proceeds further, the ECG sensor dongle can be made IoT device.

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