The Design of a Portable ECG Measurement Instrument Based on a GBA Embedded System

Jia-Ren Chang Chien
Member, IEEE
Department of Electrical Engg.
National ChengKung University
Tainan, Taiwan
n2891148@mail.ncku.edu.tw

Cheng Chi Tai
Member, IEEE
Department of Electrical Engg.
National ChengKung University
Tainan, Taiwan
ctal@mail.ncku.edu.tw

Presented by: Swapneel P. Chitale
ECGR 6185 Advanced Embedded Systems
January 30th , 2013

Agenda

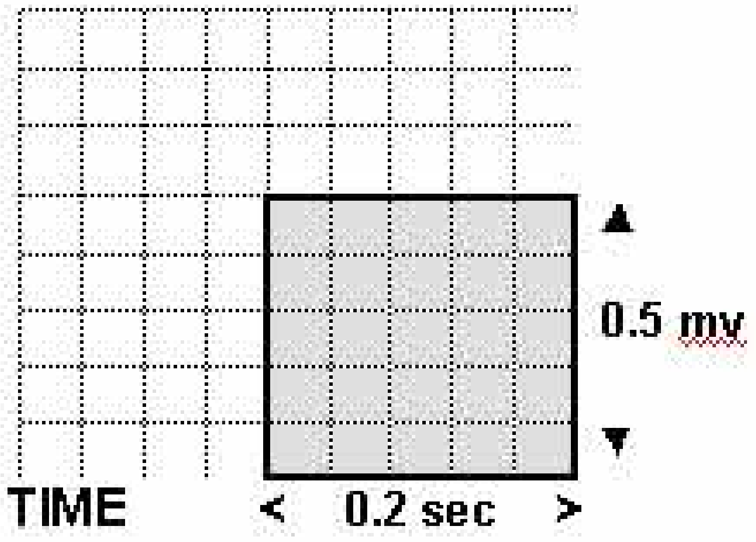
- Motivation
- Basic Electrocardiography
- Heart: An Electrical system
- Functional Block Diagram
  - ECG Detector Circuitry
  - CPLD
  - A / D Converter
  - Game Boy Advance
  - System Memory and I/O Address Map
- Software Implementation
  - Improved PQA
- Complete ECG Measurement System
- Results and Discussion
- Heart Rate Computation Improvement
- Comparison of Traditional and Proposed System
- Conclusion
- Refrences

Motivation

- Traditional ECG System's Shortcomings:
  - Bulky
  - Non-Portable
  - High Cost
- Scope for Improvement in ECG Measurement Algorithm
  - Improvement in Navakatikyan's Peak Quantification Algorithm
- Selection of GBA over PDA for Device Display
  - Impressive Plotting Results
  - No serious transmission delays
  - Fine Graphic Processing Capability

Basic Electrocardiography

- Electrocardiogram records Electrical activity of large mass of atrial & ventricular cells as specific waveforms & complexes
- ECG monitor: Voltmeter that records Electric Potentials generated by cyclic depolarization & repolarization of heart muscle
- Electrical activity measured visually by electrodes connected by cables to ECG machine
- ECG recording graph:
  - X axis : 1 unit = 0.04 seconds
  - Y axis : 1 unit = 0.1 mVolts



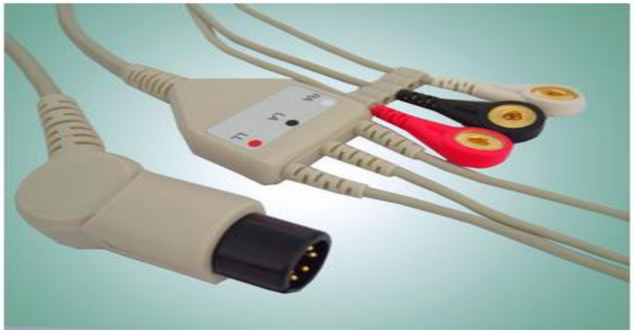
❑ ECG Lead Selection:

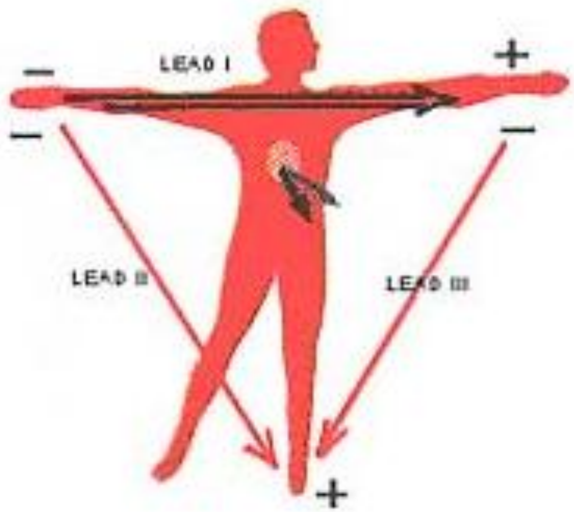
- ECG Lead: Record of electrical activity between two electrodes accurately, it provides the average current flow value at a given time in a heart section
- Electrical Description of ECG:
  Current Indication by a Stylus attached to a Galvanometer connected between
  +ve & -ve electrode leads
- Total Leads : 12 (Limb : 6, Chest : 6)
  Limb Leads Selected: I, II, III
- Reason:
  Einthoven's Law: Potential differences measured between the bipolar leads measured simultaneously, at any moment, will give

$$II = I + III$$

  Einthoven's Triangle: An Equilateral Triangle Model using standard Limb Leads for Normal ECG measurement

picture:ECG electrodes



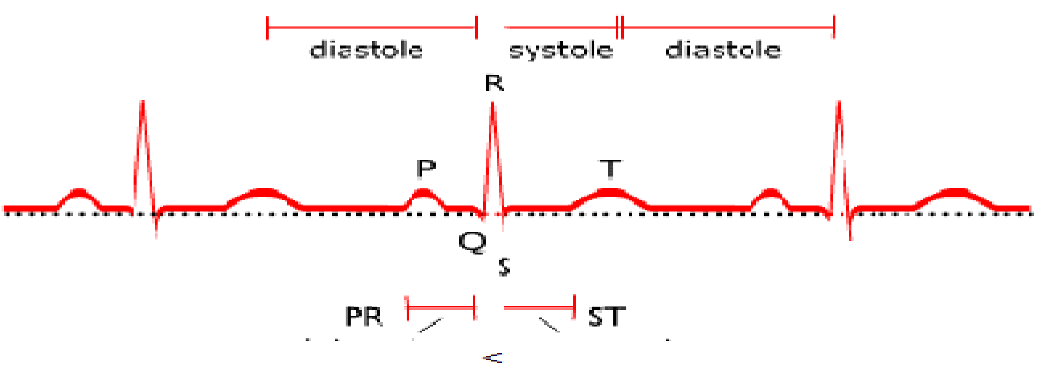


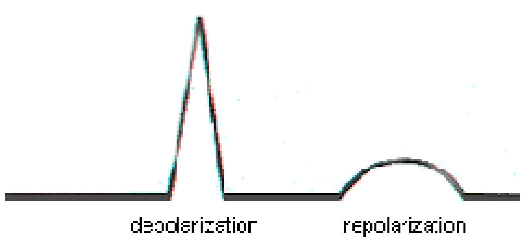
Lead I measures the voltage from Right arm to Left arm

Lead II measures the voltage from Right arm to Left foot

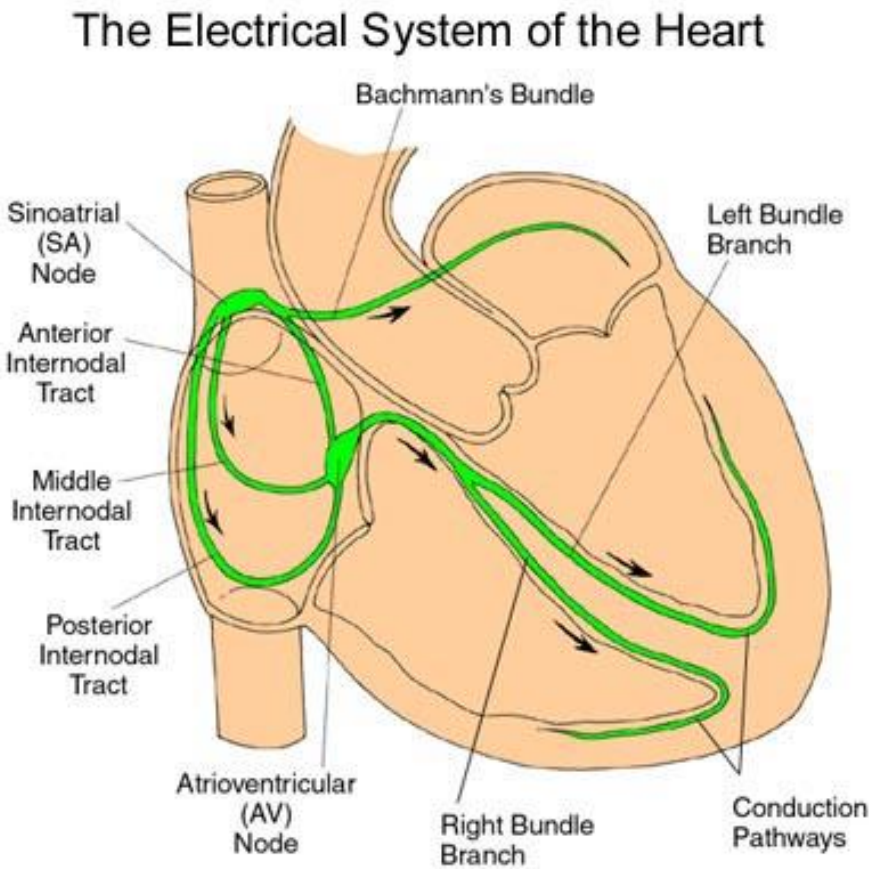
Lead III measures the voltage from Left arm to Left foot

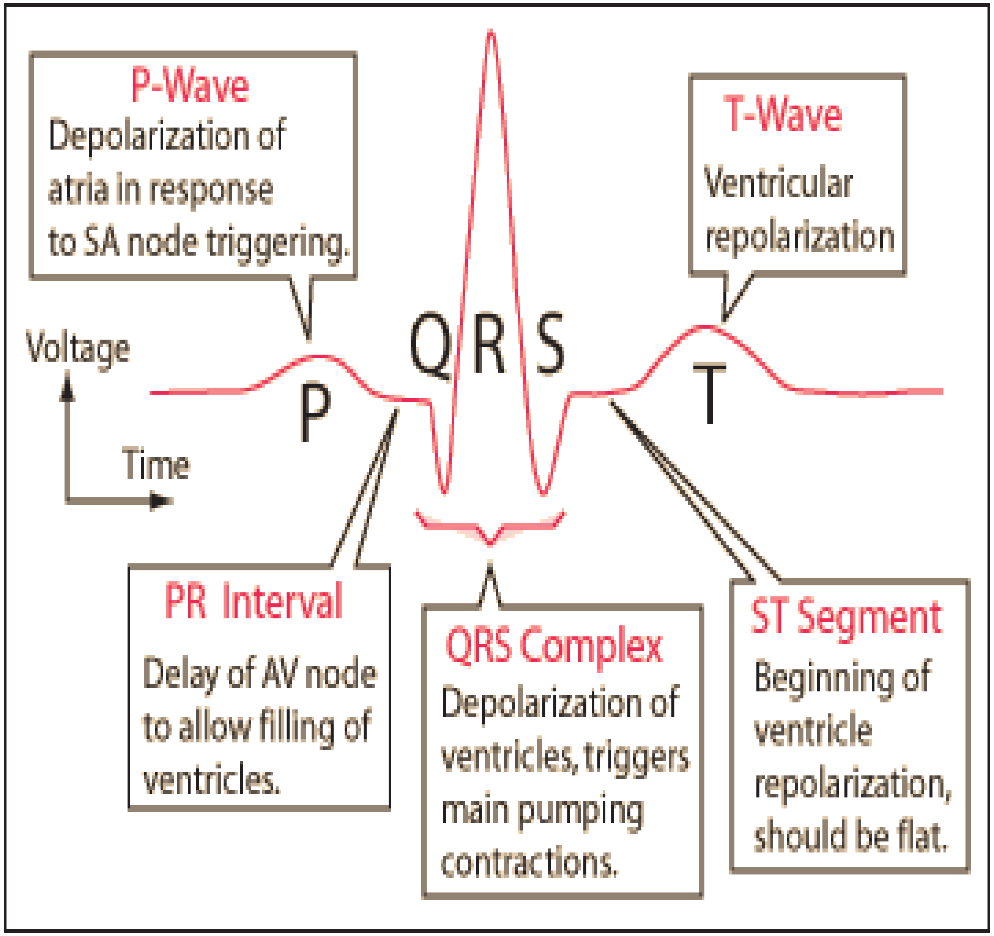
- ❑ Normal Electrocardiogram:
- ▪ Depolarization wave approaching a +ve electrode produces +ve upward ECG deflection.





Heart: An Electrical System





Electrical Overview of Heartbeat

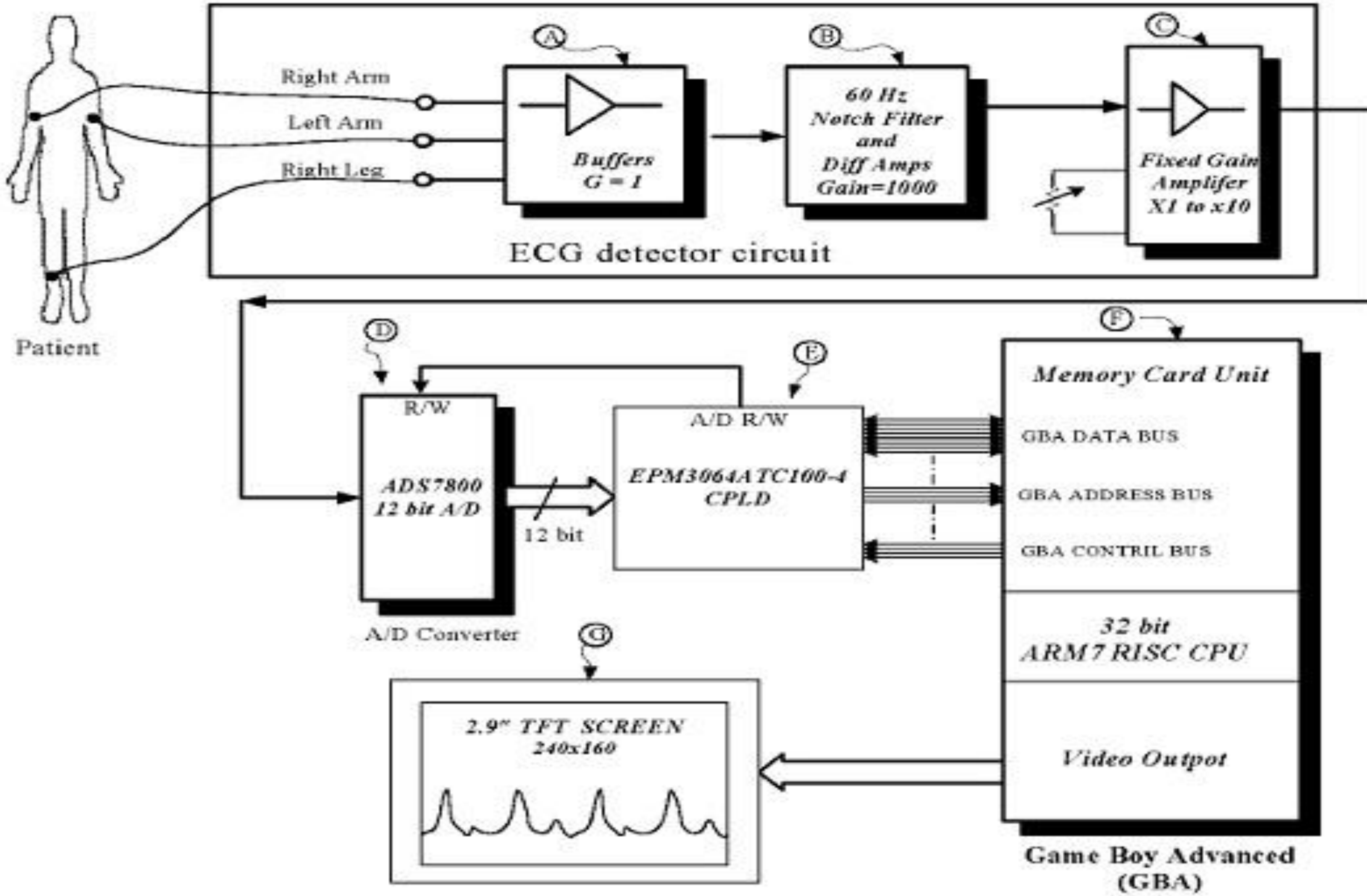
- Electrical Impulse Generation by SA node (60-100 times/minute)
- Right & Left Atria stimulated (depolarized) & contract for some time pumping blood into ventricles (P Wave)
- Impulse travels from SA to AV node thru Conduction pathways
- Impulse slow down briefly, allows ventricles to be filled with blood (PR interval)
- Impulse reaches ventricles via Bundle of His
- Bundle divides impulse into right & left ventricle
- Ventricles get depolarized and triggers main pumping contraction (QRS Complex)
- Ventricles' blood pumping slowly diminishes, as they get repolarized (ST Segment)
- Ventricles fully repolarized and ventricle blood pumping stalled (T Wave)
- Above process occurs 60-100 times/minute

Each contraction of Ventricle = One Heart Beat

- Calculation of Heart Rate:

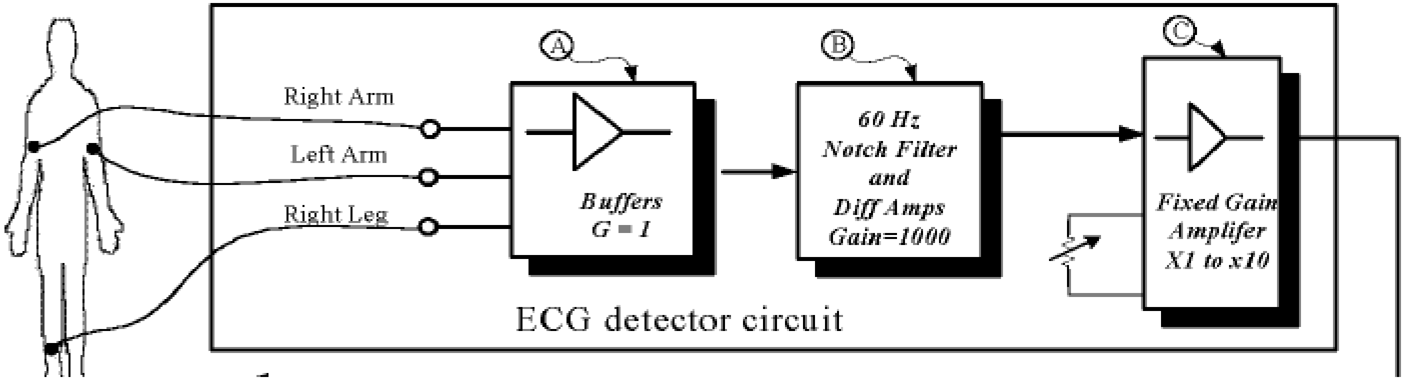
Heart Rate = (No. of R waves in 6 inch ECG strip) * 10

Functional Block Diagram



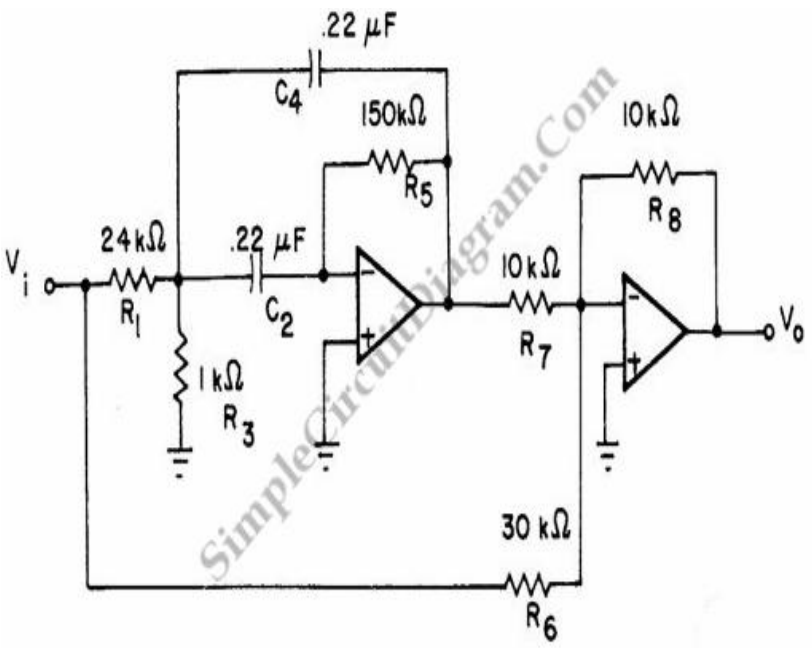
ECG Detector Circuitry

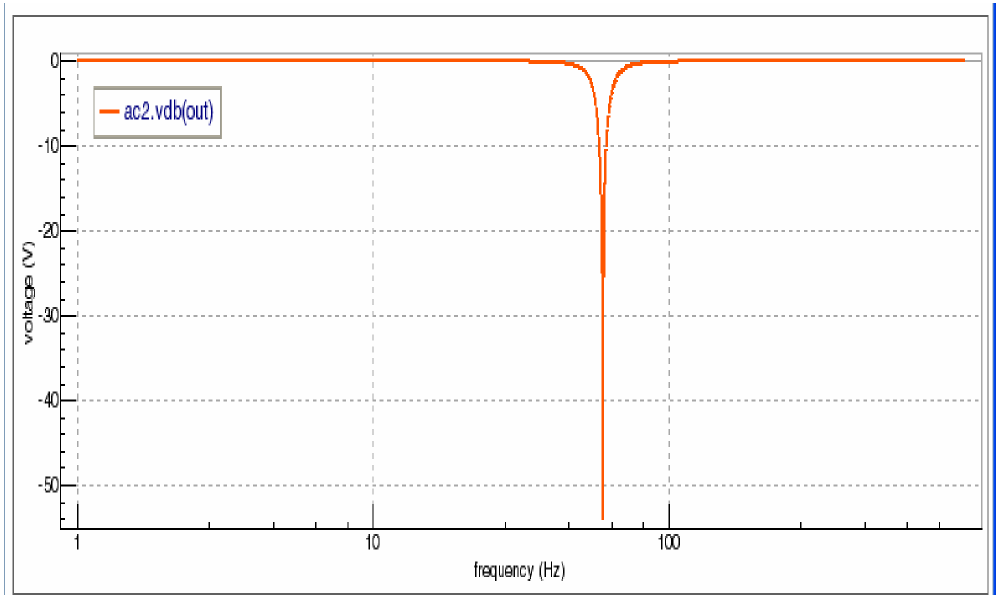
- Placement of 3 ECG electrodes:
  Right Arm, Left Arm and Left leg of person
- Prevention of Pre & Post stage Signal Interference by adding a 1:1 Buffer
- Notch Filter and Diff. Amplifier:
  - Amplification of 1mV p-p signals by a Gain=1000 Amplifier
  - Filtration of 60 hertz noise interferences using Notch Filter



❑ Notch Filter:

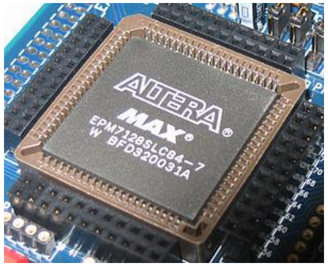
- Notch Filter removes signals from a certain frequency point or within a small frequency spectrum
- Notch filter output = Input signal – Band pass filter output
- Notch frequency = 60 hertz





CPLD

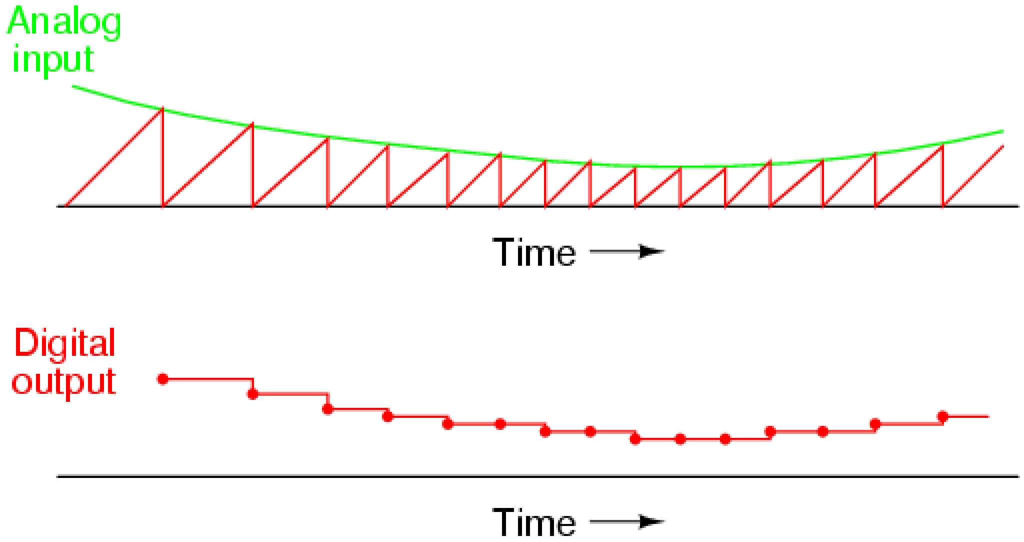
- CPLD is a programmable logic device with complexity between PAL and FPGA which works as a chipset
- Non-Volatile Memory:
  This feature is used to perform 'boot loader' functions for devices without this feature
- ALTERA EPM3060ATC100 CPLD used



- Function:
  Compiled code from computer would be put in GBA memory via CPLD's GBA ROM LOADER
- GBA ROM Loader used to directly download revised & debugged software application programs on GBA's memory card (without use of an IC programmer to burn)
- GBA executes functions in compliance with Computer

A/D Converter

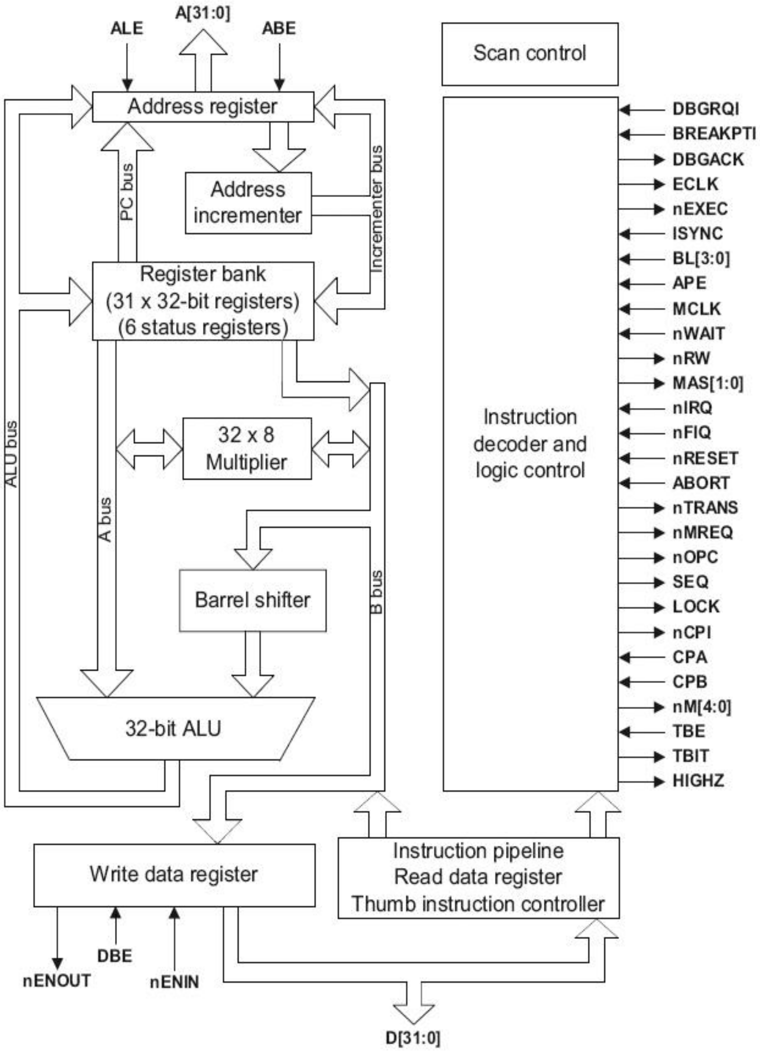
- Burr-Brown's ADS7800 IC used
- 12 bit ADC with sampling frequency = 333 khz
- ADC's R/W pin connected with GBA memory card's ECG I/O memory via CPLD
- Notch filtered & amplified ECG signal is quantized by ADC
- ECG detection Algorithm used governs the use of Quantization technique



Game Boy Advance

- Portable Gaming Device mainly focusing on 2D /3D games
- Specifications:
  - Size : 14.4 * 2.4 * 8.2 cms
  - Mass: 140 grams
  - Screen: 2.9 inch reflective TFT color LCD
  - Power: 2 AA batteries
  - Avg. Battery life : 15 hours
  - CPU : 16.8 MHz 32 bit ARM7TDMI with Embedded Memory
  - Resolution: 240 * 160 pixels
  - Color Support: 15 bit RGB
    (Char mode: 512, Bitmap mode: 2^15 simultaneous colors)

- ARM7TDMI (ARM7- Thumb+Debug+Multiplier+ICE
- Specifications:
  - 32 bit RISC CPU
  - Processing Speed: 130 MIPS
  - 32/16 bit ARM/Thumb instruction sets
  - Von Neumann-v4T Architecture
- Applications:
  - Dlink Wireless ADSL Routers
  - Nintendo's Game Boy Advanced
  - iRobot's Roomba vacuum cleaners
  - Apple's ipod
  - Sirius Satellite Radio receivers

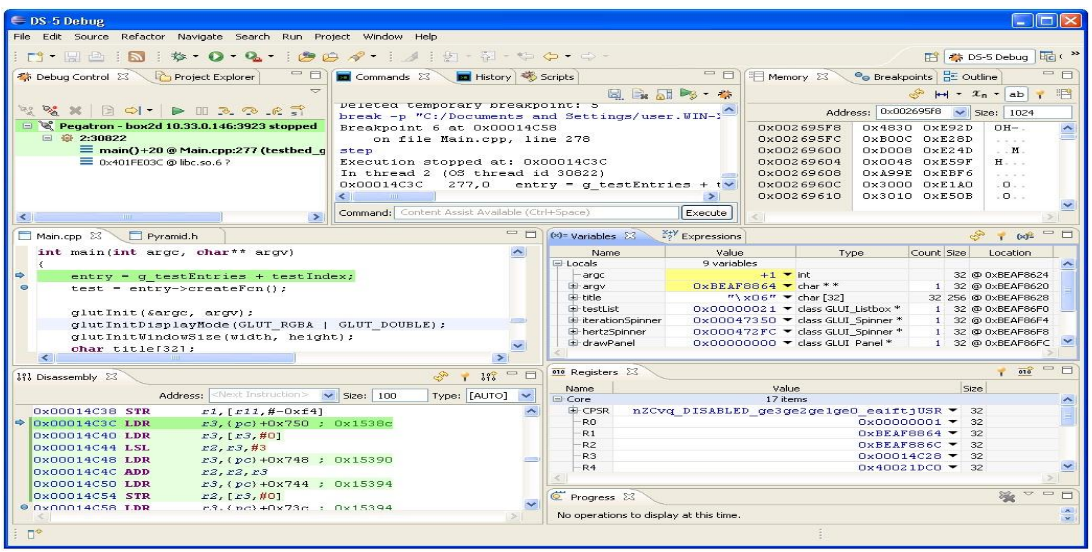


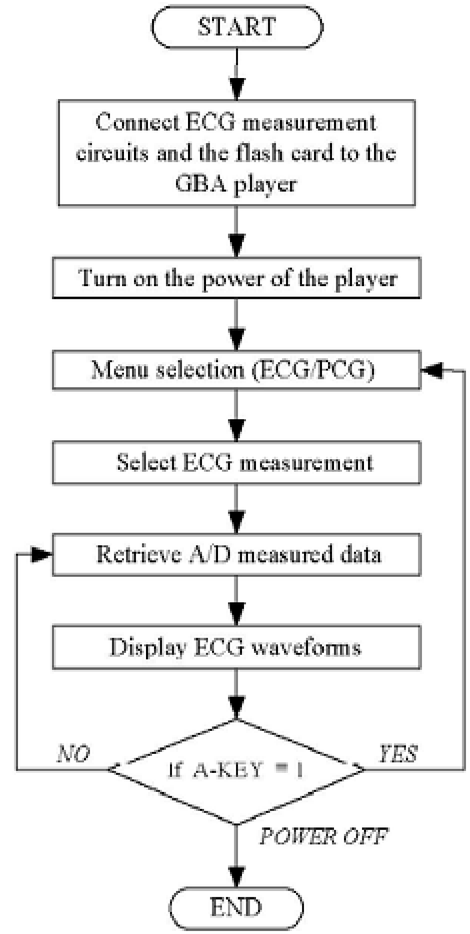
System Memory and I/O Address Map

Description	Base	Size	Width	Used to store
System ROM	&00000000	16 Kbytes	8/16/32	GBA bios program, no user access
Work RAM	&03000000	256Kbytes	8/16/32	GBA temp values (variables, stack flags)
I/O Register	&04000000	1 Kbytes	8/16/32	Control all GBA system Interface operations
Palette RAM	&05000000	1 Kbytes	16/32	Background & Sprite Palette
Video RAM	&06000000	96 Kbytes	16/32	Graphics and maps
Sprite RAM	&07000000	1 Kbytes	16/32	All sprite attributes
Flash ROM	&08000000	32 Mbytes	8/16/32	ECG measurement software (I-PQA)
CMOS RAM	&0E000000	16 Kbytes	8	Temp. ECG values
ECG I/O (A/D)	&0E004000	16 Bytes	8	Control ADC with CS,INT,R/W pins
ECG I/O (PC)	&0E004010	16 Bytes	8	Communication addresses of system & PC
ECG I/O (System)	&0E004020	4 Kbytes	8	Control Peripherals (LED, Pushbuttons)

Software Implementation

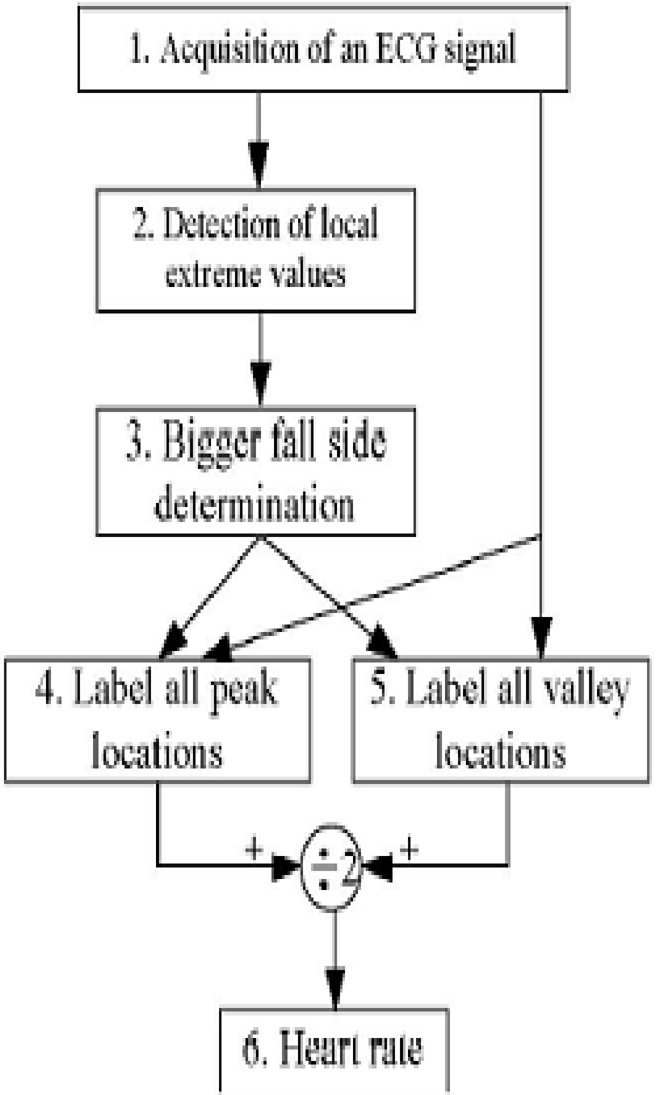
- C code compiled with ARM Developer Suite Software on PC
- PC code sent to GBA for execution via CPLD ROM LOADER
- Major Software Functions:
  - Data Transmission betn. PC-GBA
  - Display Menu Selection: ECG/PCG
  - Display physiological information
  - Control system hardware





Improved - PQA

- Navakatikyan proposed the ECG Peak detection algorithm
- Improved 'Bigger Fall side Detection' used to rectify the threshold errors of Navakatikyan's Algorithm
- New Algorithm: I-PQA
  Improved Peak Quantification Algorithm
- System Calibration:
  - HP 33120A Signal Generator sends1mV pulses to ECG detection circuit's input term.
  - Simulated input's amplitude used for calibration



❑ I-PQA steps:

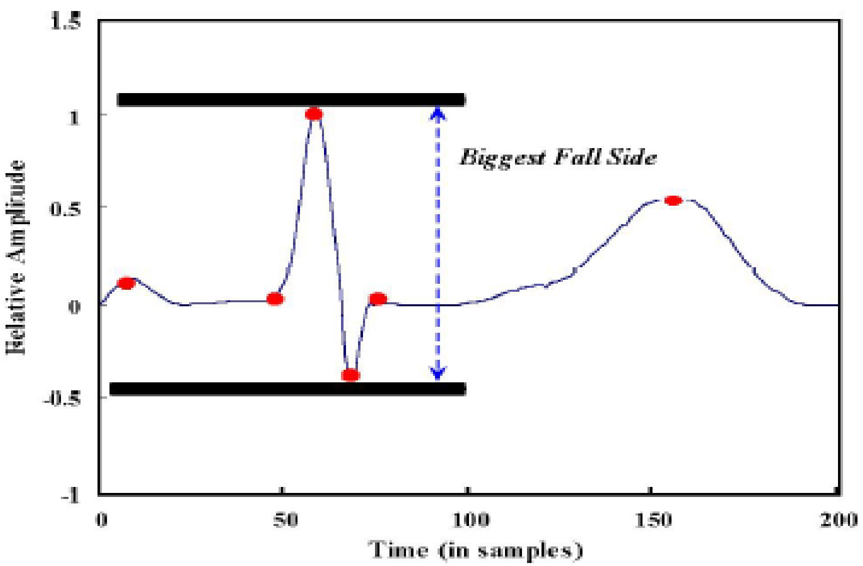
1. Search & Record magnitudes & locations of maximas, minimas and turning points from an ECG signal chunk
2. Delete all turning points between maxima and minima
3. Heart rate = (Peak value + valley value) / 2

❑ Bigger Fall Side Detection for extreme values location:

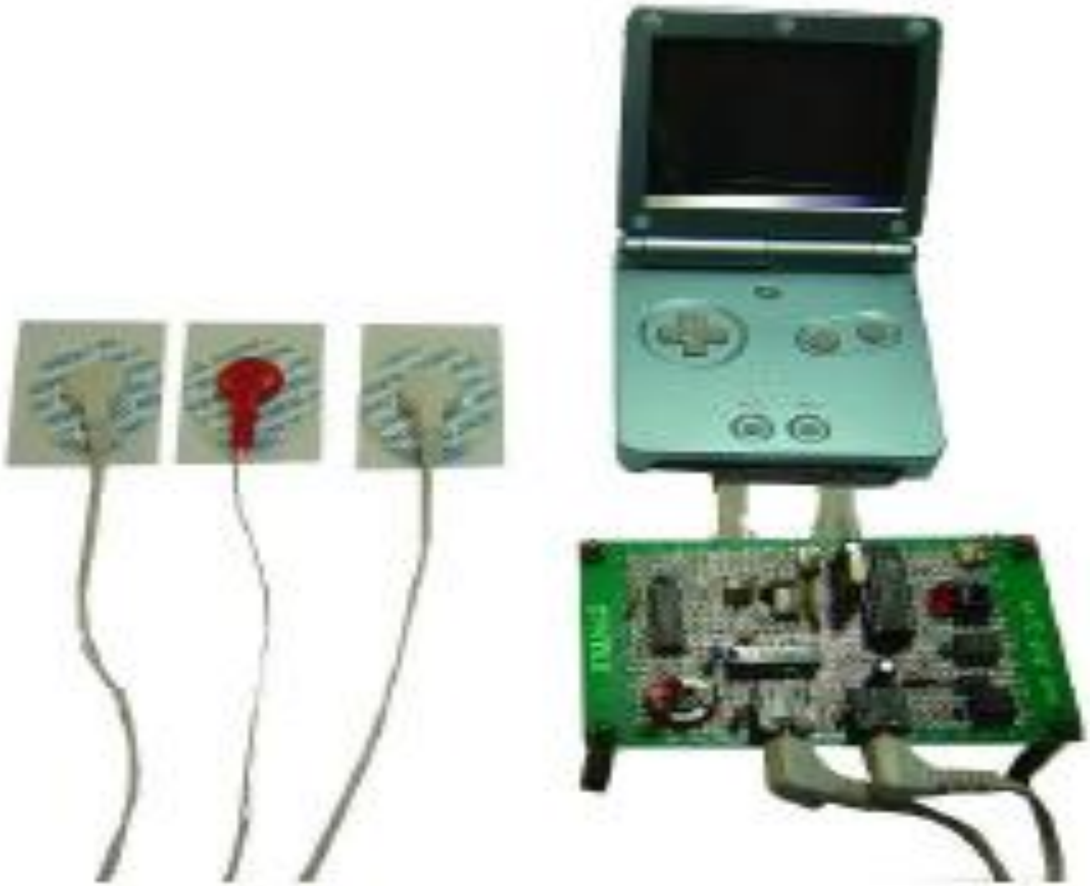
- PQA's threshold related errors corrected

$$BFSD = \begin{cases} MAX(j) = MIN(j) = F(j,n) & ,if\ n=1 \\ MAX(j) = F(j,n+1) & ,if\ F(j,n+1) >= MAX(j) \\ MIN(j) = F(j,n+1) & ,if\ F(j,n+1) < MIN(j) \end{cases} \quad (1)$$

where $F(j, n)$ designates the jth ECG waveform's extreme value; $MAX(j)$ the jth ECG waveform's peak value; $MIN(j)$ the jth ECG waveform's valley value.



Complete ECG Measurement System



Results and Discussion

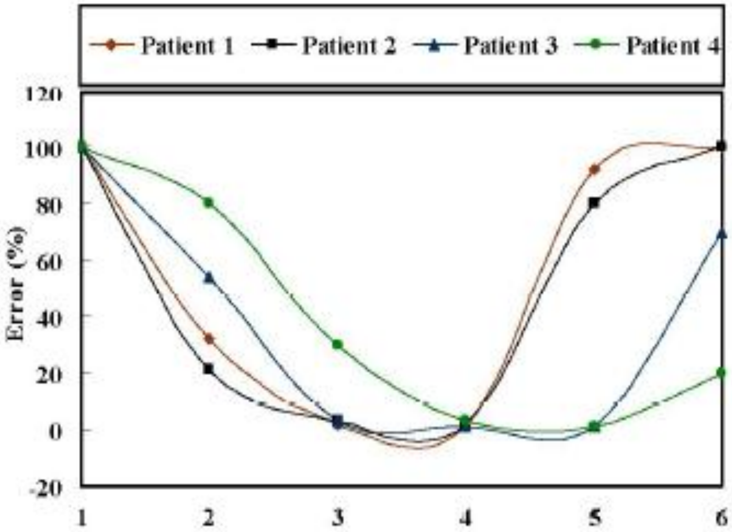
- Current System has accomplished ECG measurement System
- Future Improvement:
  - Addition of PCG (Phonocardiogram) to examine Heart murmurs
  - ECG/PCG switching: Increased accuracy of heart disease location
- Screen displays P,Q, R, S, T waves continuously
- Screen displays following message at bottom:
  HR: 71 BPM (Beats Per Minute)

Heart Rate Computation Improvement

- If Electrodes shift or Incorrectly Positioned, then P & T waves distort and cause measurement Errors
- Traditional Method:
  - If R wave of system exceeds Threshold = One Heart beat
  - Distortion causes P or T waves to exceed Threshold and get counted as heart beat
  - Serious Judgment Discrepancies occur if threshold inappropriately set
  - Heart Rate Discrepancy data:

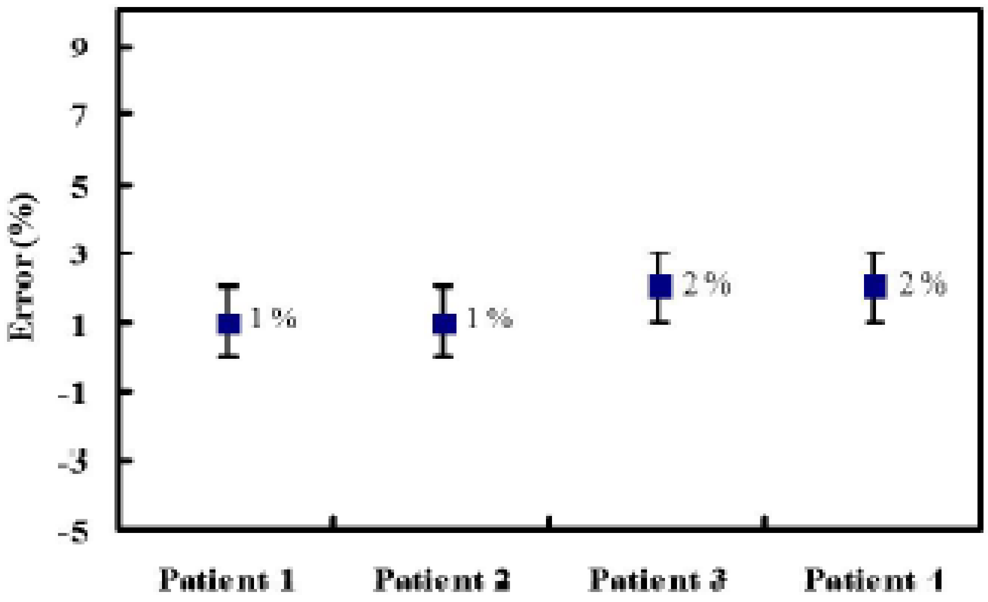
THE COMPUTATIONAL DISCREPANCIES INCURRED WITH DIFFERENT PRESET THRESHOLD VALUES

	Error (± 1%)			
Threshold (volt)	*Patient 1*	*Patient 2*	*Patient 3*	*Patient 4*
1	100 %	100 %	100 %	100 %
2	32 %	22 %	54 %	83 %
3	2 %	3 %	3 %	31 %
4	1 %	2 %	1 %	3 %
5	100 %	100 %	1%	1 %
6	100 %	100 %	82 %	22 %



❑ Proposed Method:

- Uses Improved PQA with Bigger Fall Side Detection
- Algorithm unaffected by Threshold magnitude, hence heart rate unaffected by Electrode Plate Placement Problems
- Experimental Results reveal:
  Rapid and finely accurate Computation of Heart Rate



Comparison of Traditional & Proposed System

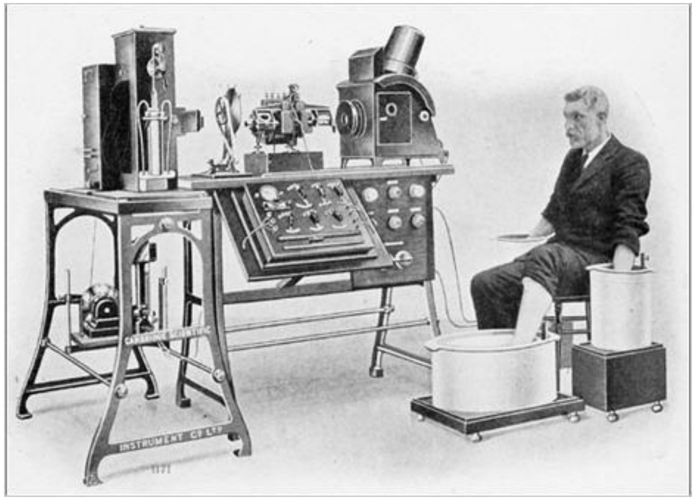
Difference Type	Traditional System	Proposed System
Hardware	Displays used are large and bulky	GBA Display used has small size and light weight
	Displays don’t provide sufficiently fine graphics processing capability for plotting	GBA Gaming displays have excellent graphics processing capability for plotting
	Due to its bulkiness, system isn’t portable	Small size and it’s light weight, makes the system perfectly portable
	Traditional system has a high cost	The proposed system has relatively lower cost
	Due to it’s entire 12 lead electrode assembly, system is not best for domestic use	Due to it’s simple 3 lead electrode , system is simple and hence conducive for domestic use

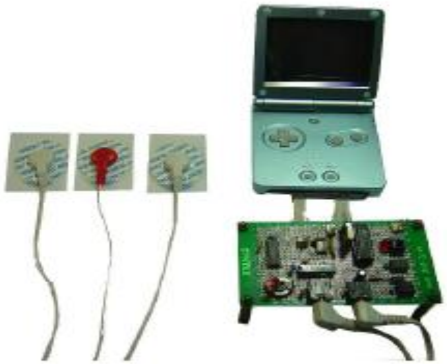
Comparison of Traditional & Proposed System

Difference Type	Traditional System	Proposed System
Software	Navakatikyan's Peak Quantification Algorithm is used	An Improvement of Navakatikyan's Peak Quantification Algorithm is used
	Thresholds are used for detecting extreme value in ECG sequence	Bigger Fall Side Determination is used for detecting extreme value
	Inappropriate choice of threshold introduces error from 22 %-100%	Independent of threshold, hence threshold based errors
	Electrode shifting or incorrect positioning introduces errors	Different locations of electrodes don't affect Heart Rate Computation
	Measurement algorithm not so reliable	Measurement algorithm reliable and accurate
	Slower upgrades, revisions & debugging due to absence of ROM LOADERs	Faster upgrades, revisions & debugging due to presence of ROM LOADERs

Conclusion

- GBA play machine coupled with I-PQA can offer extremely accurate & rapid physiological signal measurements
- Reinforcements in System:
  - Addition of Storage Devices for ECG data
  - Minimize System Dimensions
- Purpose served by Proposed System:
  - Diversification of Embedded applications in Medical Instrumentation
  - Medical Equipment for general public for a healthier society





References

1. www.members.fortunecity.com/cytunglo/cs.htm
2. www.nintendo.com
3. www.slat.org/project
4. www.arm.com
5. www.bottledlight.com
6. "A Real Time Algorithm for the Quantification of Blood Pressure Waveforms" by M Navakatikyan, C Barret, G Heads, J Ricketts and S.C Malpas
7. www.wikipedia.com
8. Photos Retrieved From:
    1. http://elec424.rice.edu/EKG/hosp_ekg.jpg
    2. http://learn.docircuits.com/wp-content/uploads/2012/12/ECG.png
    3. http://www.powersystemsdesign.com/library/resources504/images/articles/tech_talk/ti_presents_capability_power_lighting_medical/sc-10019_ads1298_2_22march10.jpg
    4. http://upload.wikimedia.org/wikipedia/commons/thumb/c/c1/ECGcolor.svg/230px-ECGcolor.svg.png
    5. http://www.ekgguru.com/sites/default/files/ecg-heart-art/Cor%20Arteries%20and%20MI%20Changes%20-%20Landscape.png
    6. http://preview.turbosquid.com/Preview/2011/09/06__12_13_12/ECG_Machine_Electrocardiograph_CareWell_05.jpgc17023ef-80d5-495b-9069-14293763bf48Large.jpg
    7. http://www.cvphysiology.com/Arrhythmias/ECG%20trace%20with%20grid.gif
    8. http://i.istockimg.com/file_thumbview_approve/3733698/2/stock-photo-3733698-electrocardiogram-ecg-ekg-with-human-heart-on-screen.jpg
    9. http://misalud.com/misalud/images/EKG.jpg
    10. http://www.adinstruments.com/sites/default/files/images/ltexp_cardiac-cycle.gif
    11. http://www.jonbarron.org/sites/default/files/images/ecg2.jpg
    12. http://www.bem.fi/book/19/fi/1901.gif
    13. http://fisica.unav.es/~jbragard/detailecg.gif
    14. http://us.123rf.com/400wm/400/400/lightwise/lightwise1201/lightwise120100092/11995650-ecg-and-ekg-cardiovascular-system-monitoring-with-heart-anatomy-from-a-healthy-body-on-black-backgro.jpg
    15. http://research.vet.upenn.edu/Portals/75/ecg_normal_sinus_rhythm.gif
    16. www.simplecircuitdiagram.com