# ECG Signal Compression Using Analysis by Synthesis Coding

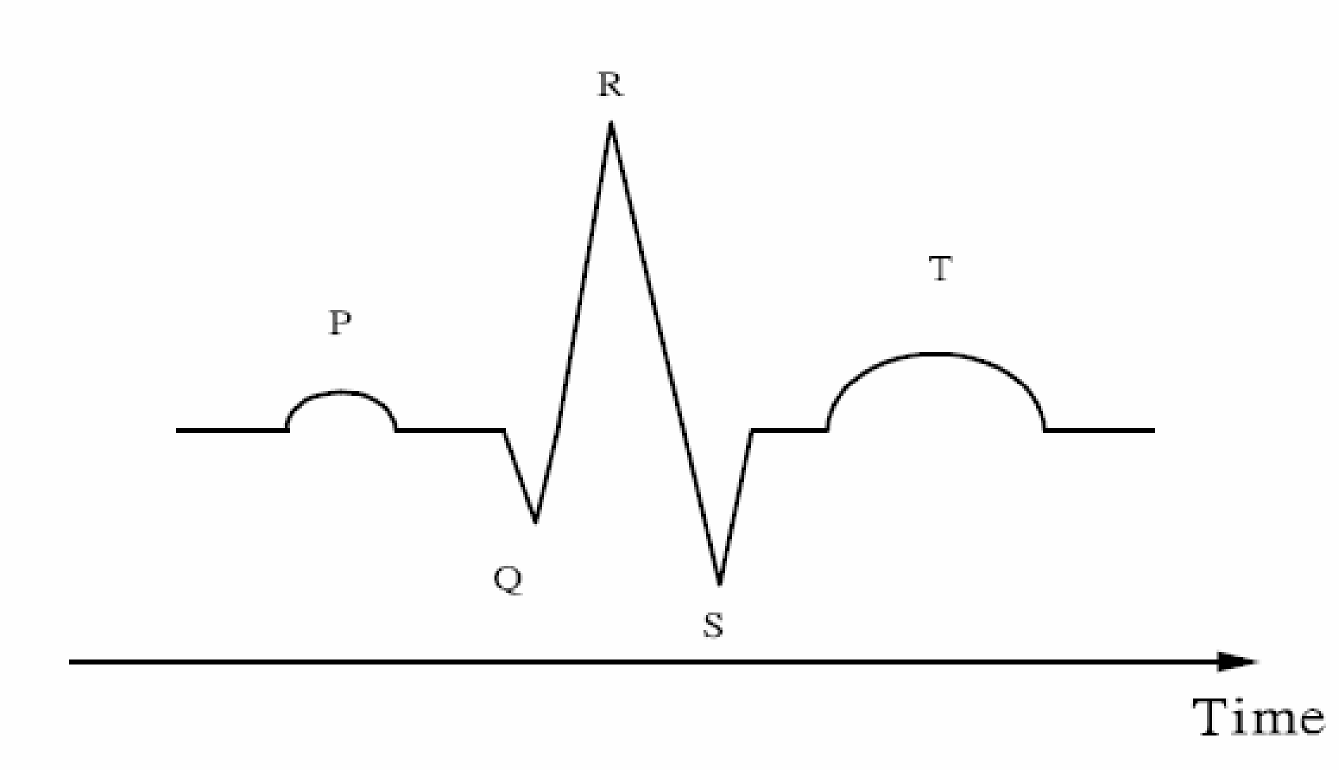
# Outlines

- Motive
- Introduction of ECG
- The distortion measures
- The compression algorithm
- Results and discussion
- Reference

# Motive

- Increasing storage capacity of ECG's as database for subsequent comparison or evaluation
- Feasibility of transmitting real-time ECG's over the public phone network
- Holter ECG signal

# Introduction of ECG



# Introduction of ECG

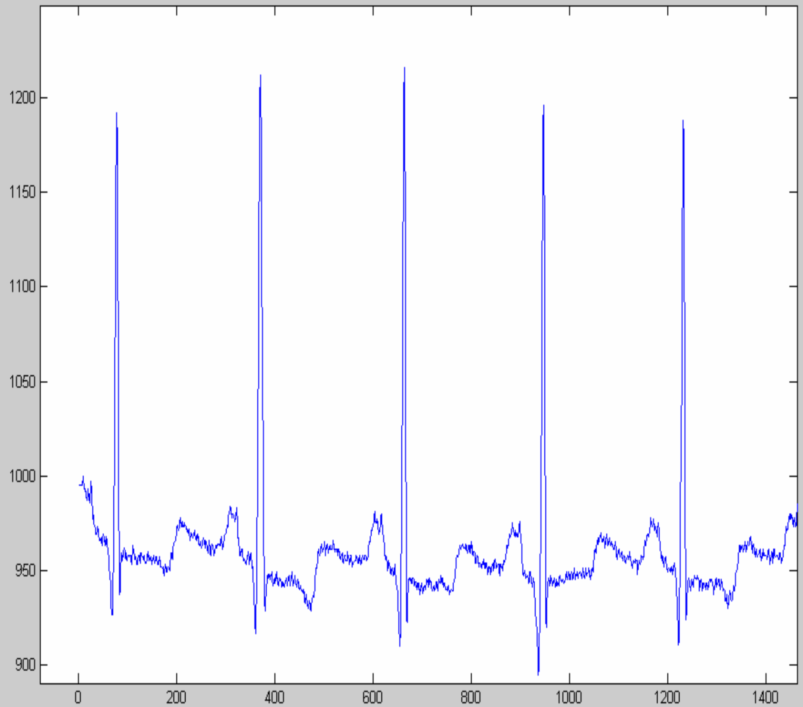
- Classical Direct Data Compression Methods
  - The amplitude zone time epoch coding (AZTEC) Technique:
  - The Fan/SAPA algorithm

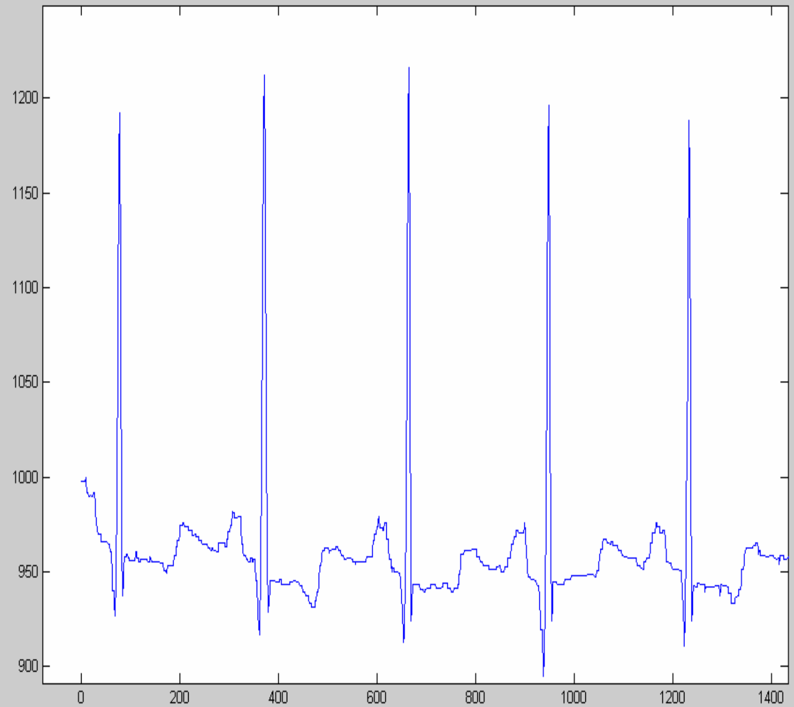
# Introduction of ECG

- The amplitude zone time epoch coding (AZTEC) Technique:
- The AZTEC algorithm converts raw ECG sample points into "plateaus" and "slopes"
- Compression ratio of 10:1 and 500Hz and PRD 28%
- However, the reconstructed signal demonstrates significant discontinuities and distortion in P and T waves due to their slow varying slopes

# Introduction of ECG

- AZTEC



# ECG Compression Techniques

- The Fan/SAPA algorithm
- Compression ratio of 3:1 and 250Hz and PRD 4%

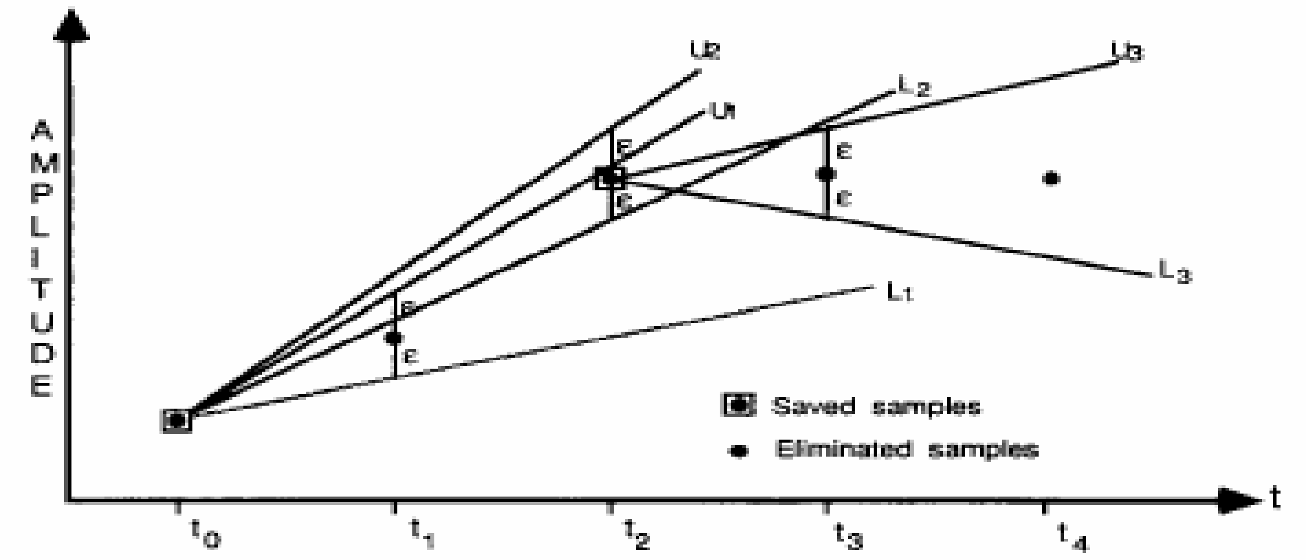
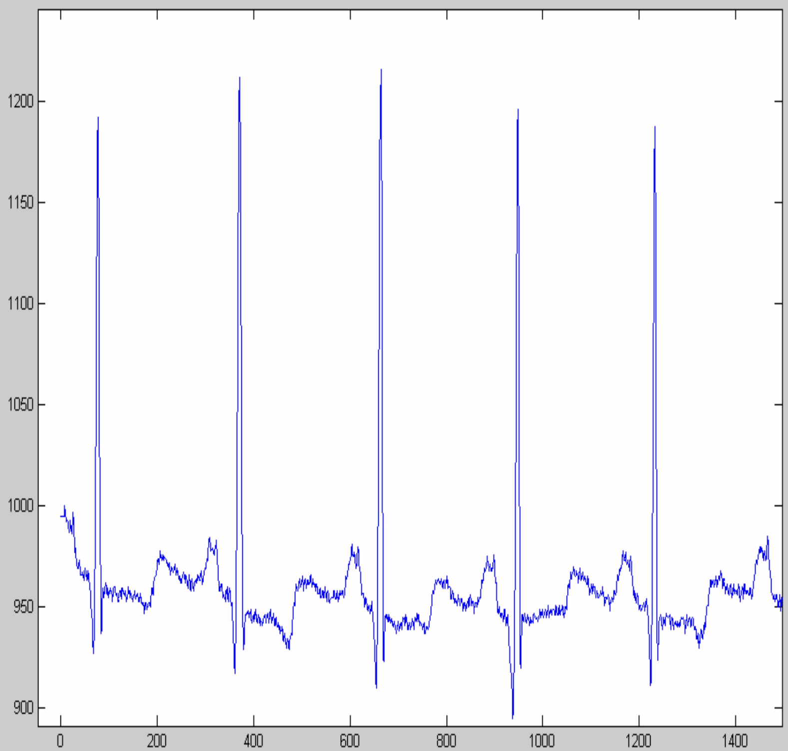
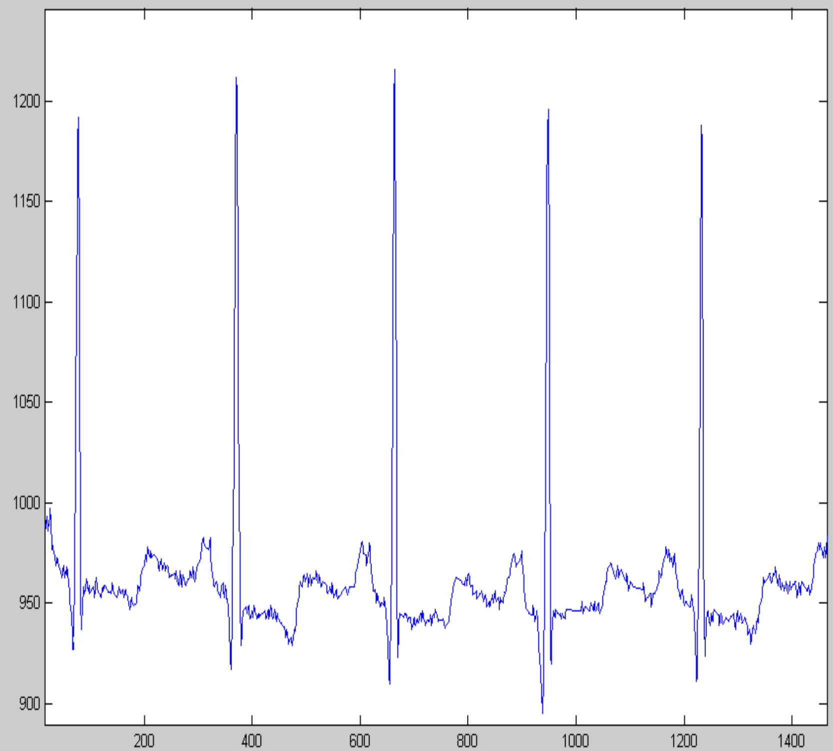



Fig. 6. Illustration of the Fan method. Upper and lower slopes ( $U$ and $L$ ) are drawn within threshold ($\epsilon$) around sample points taken at $t_1$, $t_2$, etc.

# Introduction of ECG

- FAN/SAPA



# The distortion measures

- The percent rms difference (PRD) is one of the most popular distortion measures used in ECG compression algorithm

$$PRD = \sqrt{\frac{\sum_{n=1}^{N}\left(x(n)-\tilde{x}(n)\right)^2}{\sum_{n=1}^{N} x^2(n)}} \times 100$$

- A version of PRD with different normalization

$$PRD1 = \sqrt{\frac{\sum_{n=1}^{N}\left(x(n)-\tilde{x}(n)\right)^2}{\sum_{n=1}^{N}\left(x(n)-\bar{x}\right)^2}} \times 100$$

# The distortion measures

- The PRD and other similar error measures have many disadvantages, which result poor diagnostic relevance. Therefore, the recently introduced Weighted Diagnostic Distortion (WDD) measure was also implemented in this work.
- The diagnostic features can be divided into three groups: duration features (of wave, segments, and intervals), amplitude features, and shape feature. The duration features are the most significant features in most of applications

# The distortion measures

- A vector of diagnostic parameters is defined

$$\beta^T = \left[\beta_1, \beta_2, \ldots, \beta_p\right] \qquad \hat{\beta}^T = \left[\hat{\beta}_1, \hat{\beta}_2, \ldots, \hat{\beta}_p\right]$$

- Where p is the number of features in the vector and the diagnostic parameters were chosen to be:

$$RR_{\text{int}}, QRS_{dur}, QT_{\text{int}}, P_{dur}, PR_{\text{int}}, QRS_{peak\_no}, Q_{wave\_exsist}, \Delta_{wave\_exsist},$$

$$T_{shape}, P_{shape}, ST_{shape}, QRS^{+}_{amp}, QRS^{-}_{amp}, P_{amp}, T_{amp}, ST_{elevation}, ST_{slope}$$

# The distortion measures

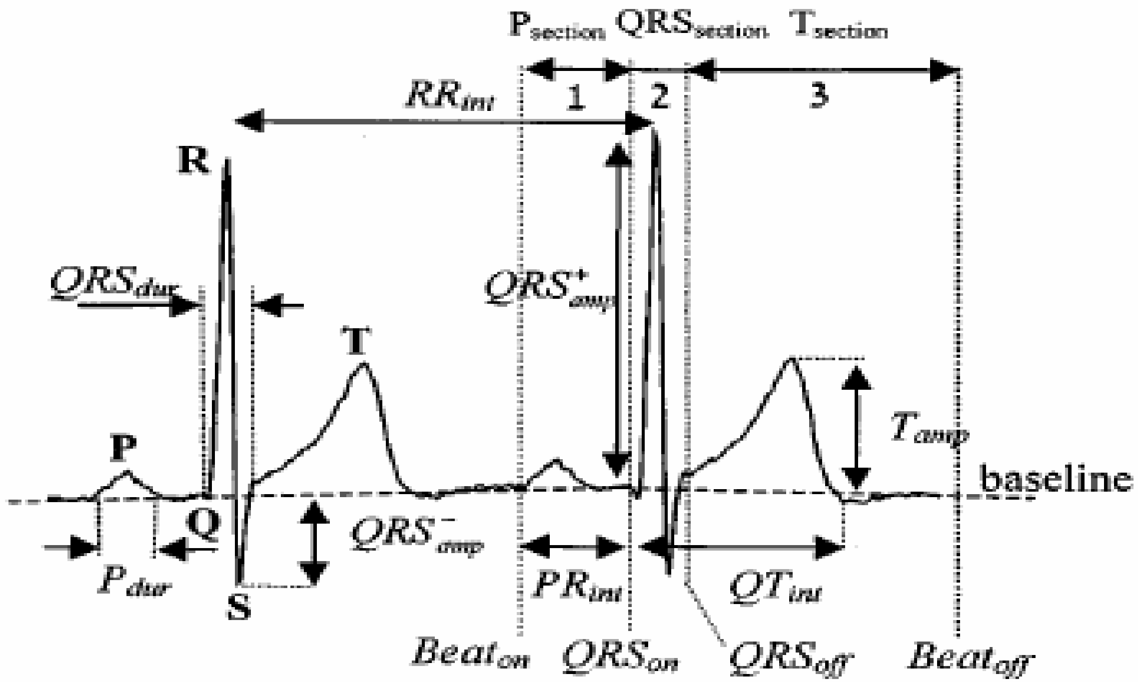



Fig. 1. Some of the diagnostic features used by the WDD (and beat segmentation).

# The distortion measures

- The Weighted Diagnostic Distortion between these two vector is:

$$WDD\left(\beta,\hat{\beta}\right)=\Delta\beta^{T}\cdot\frac{\Lambda}{tr\left[\Lambda\right]}\cdot\Delta\beta\times 100$$

- Where $\Delta\beta^{T} = \left[\Delta\beta_{1},\ldots,\Delta\beta_{p}\right]$
- And $\Delta\beta$ is the normalized difference vector
- And $\Lambda = diag\left[\lambda_i\right] \;;\; \lambda_i > 0 \quad \left(i = 1,2,\ldots,p\right)$

# The distortion measures

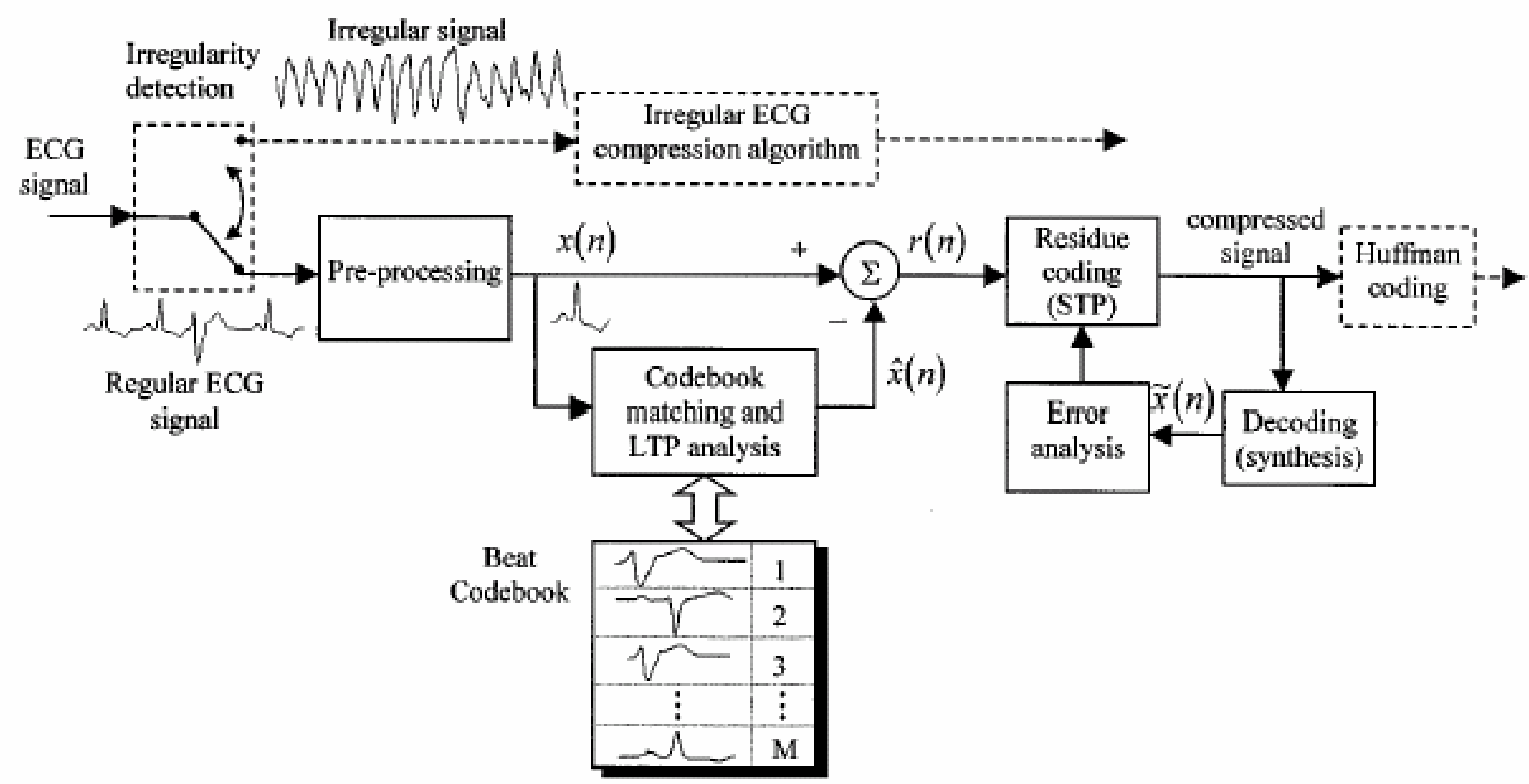
- Every scalar in this vector gives distance between the original signal feature and the reconstructed signal feature.

$$\Delta \beta_i = \frac{\left| \beta_i - \hat{\beta}_i \right|}{\max \left\{ \left| \beta_i \right|, \left| \hat{\beta}_i \right| \right\}}$$

# The compression algorithm

- The ECG signal is first classified into one of two types: 1. Regular PQRST complex ECG signal, or to 2. Irregular ECG signal
- The ASEC algorithm consists of three main subsystems: 1. preprocessing, 2. coding: codebook matching and long-term prediction (LTP), residue coding, error analysis, and 3. decoding

# The compression algorithm



# The compression algorithm

- The Preprocessing stage
- The Preprocessing stage consists of segmentation, nonuniform filtering, and baseline remove.
- Segmentation: every beat is further divided into the three section $P_{\sec tion}, QRS_{\sec tion}, T_{\sec tion}$
- Nonuniform filtering: consists of two different finite impulse response (FIR) filters. The P and T section is filtered with 0.01-50 Hz bandpass FIR filter, and QRS section is filtered with 0.1-100 Hz FIR filter.

# The compression algorithm

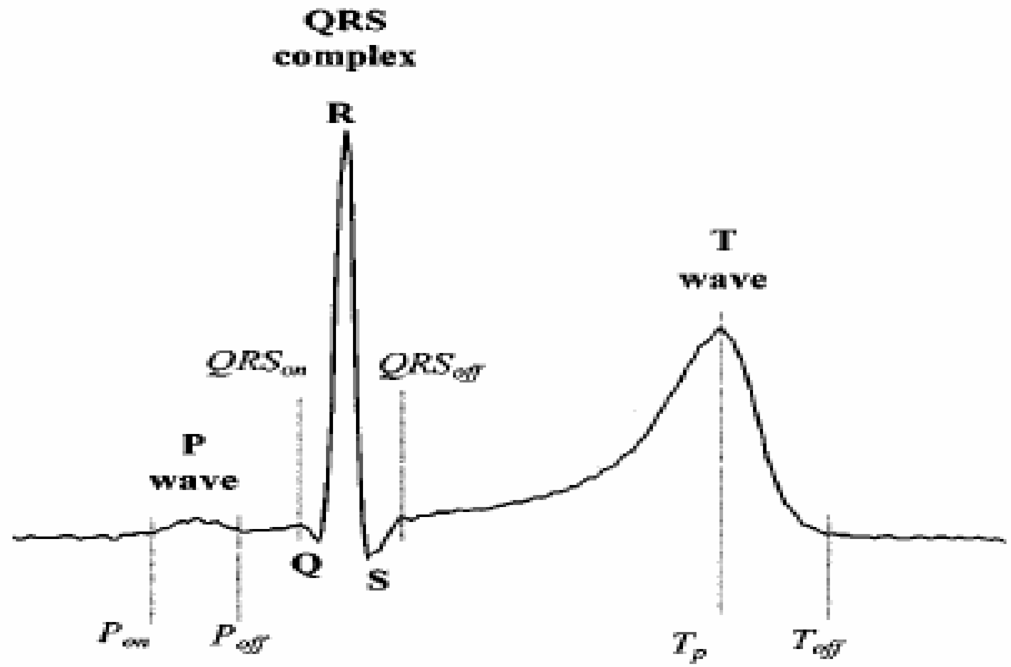
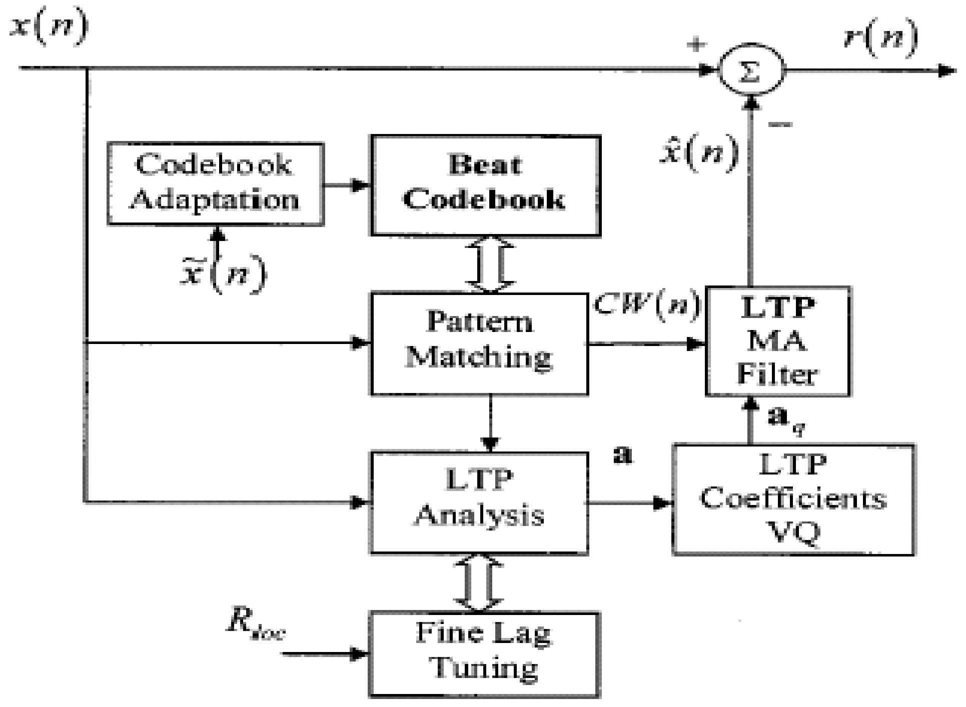



Fig. 2. PQRST waves and location points of one beat.

# The compression algorithm

- The Encoding System
- Long-term prediction

$$\hat{x}(n) = \sum_{i=-p}^{p} a_i x(n - \alpha + i)$$

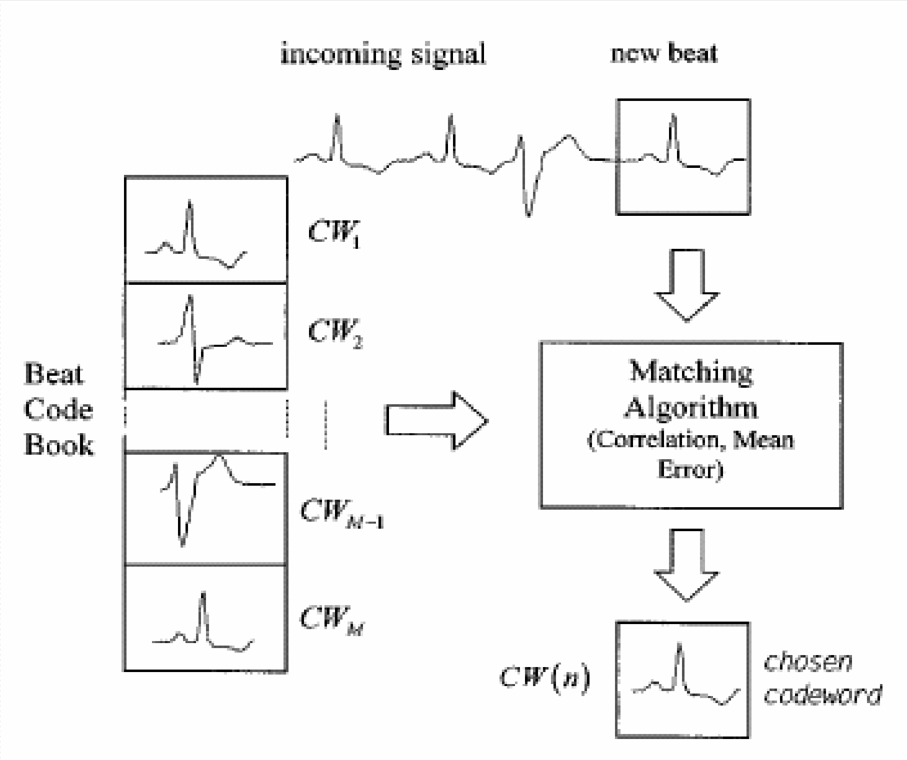


# The compression algorithm

- The Encoding System
- Best matched codeword

$$j = \arg\min_{i=1,2,\ldots,M} \{E_i\}$$

$$CW(n) = CW_j(n)$$



# The compression algorithm

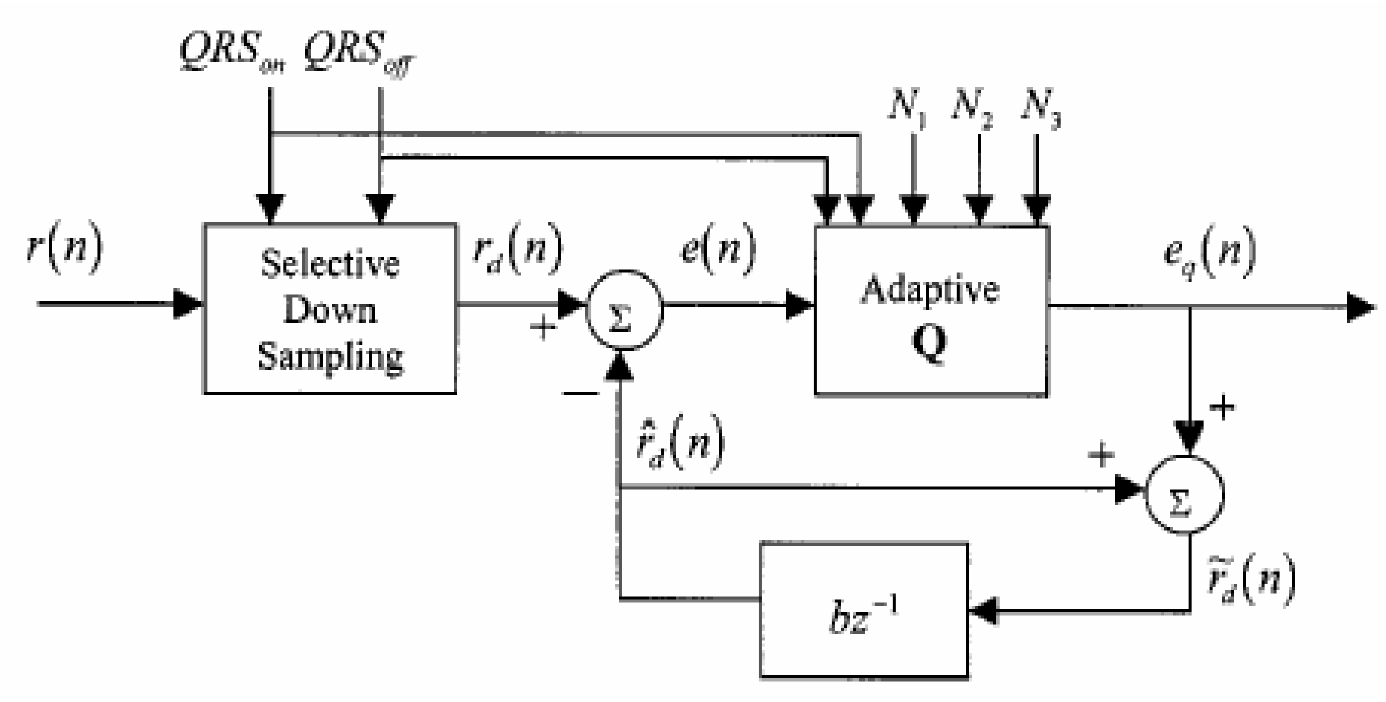
- Two types of codebooks were considered in this work:
  1. Universal codebook: requires the identification and clustering of the beats of the database and will require more than eight beats.
  2. Individual codebook: design for a specific subject. The codebook may be acquired by starting with universal codebook and adapting the codeword to fit the specific subject.
- In this work:

$$CW_j^k = \theta \cdot CW_j^{k-1} + (1-\theta)\tilde{x}$$

# The compression algorithm

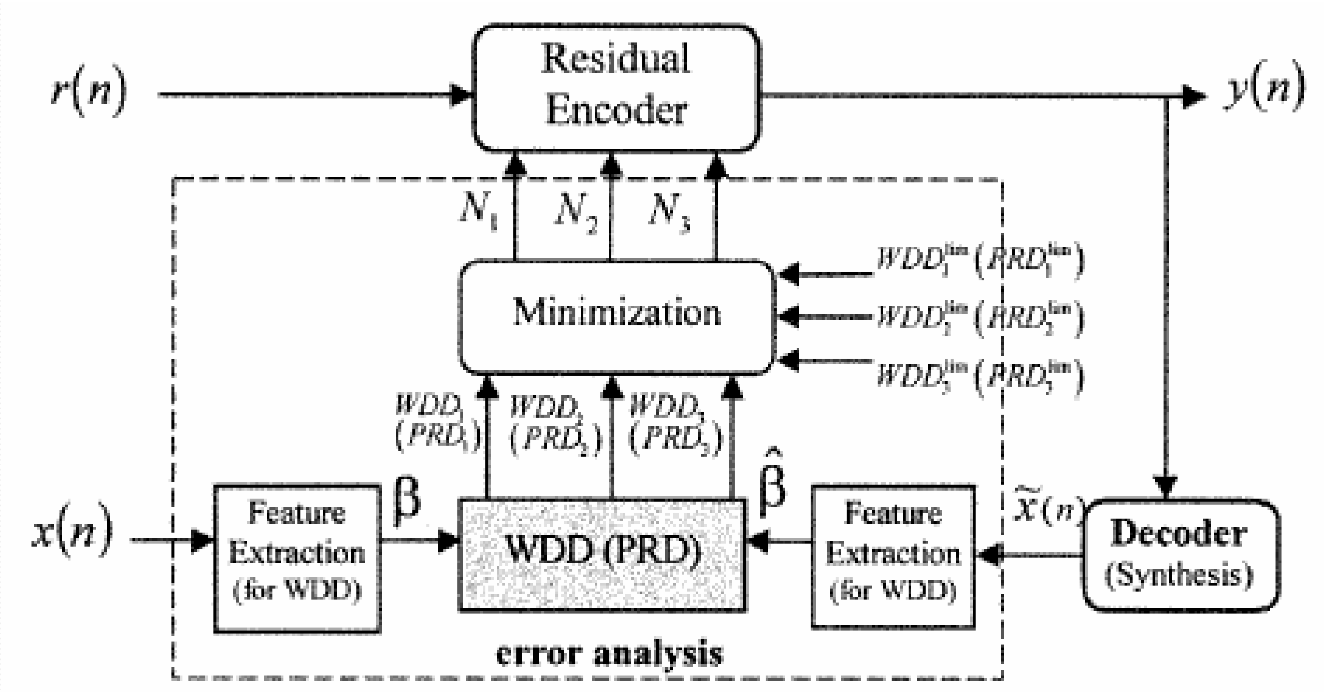
- The Residue Encoder:
- The pervious stage: down sampling by a factor by two (to 125Hz) in $T_{\sec tion}$ and in $P_{\sec tion}$ and short time correlation reduction by a DPCM with a first-order linear predictor.
- The uniform quantizer separately quantizes every section : P with N1, QRS with N2, T with N3 bits/sample. These values (N1,N2,N3) are determined by the error analysis subsystem.

# The compression algorithm



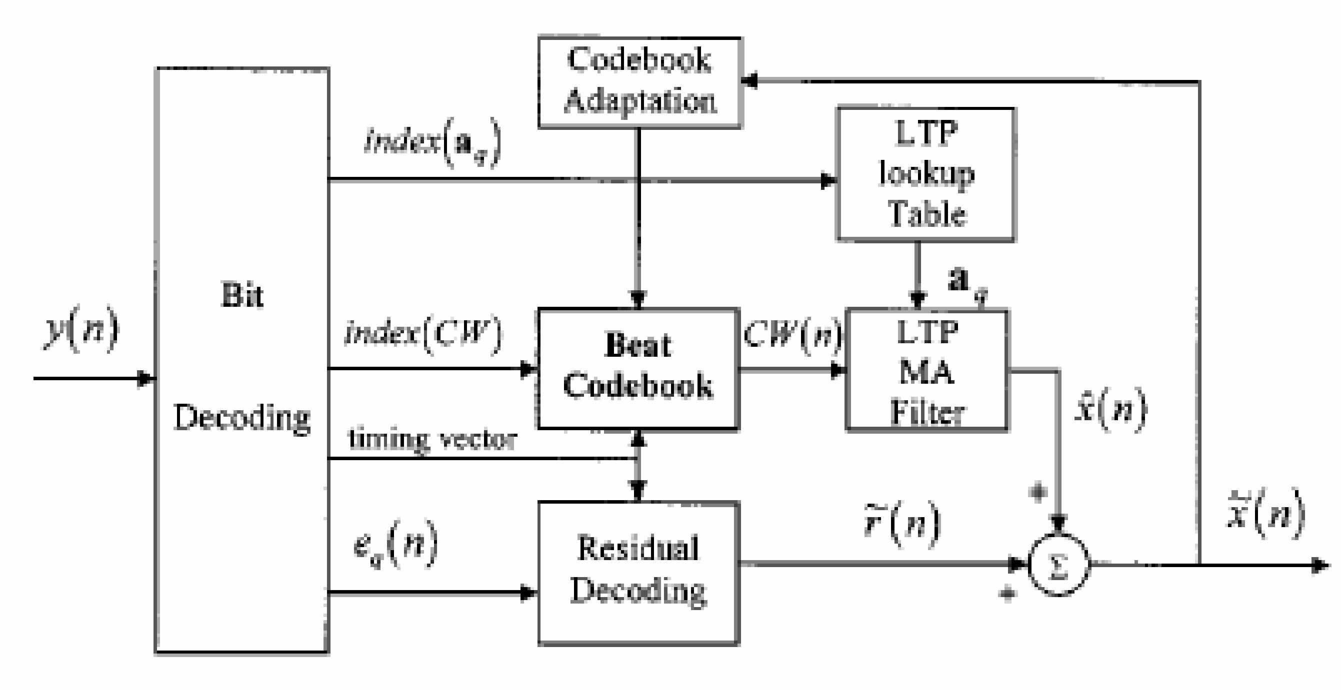
# The compression algorithm

- Error analysis by signal reconstruction:

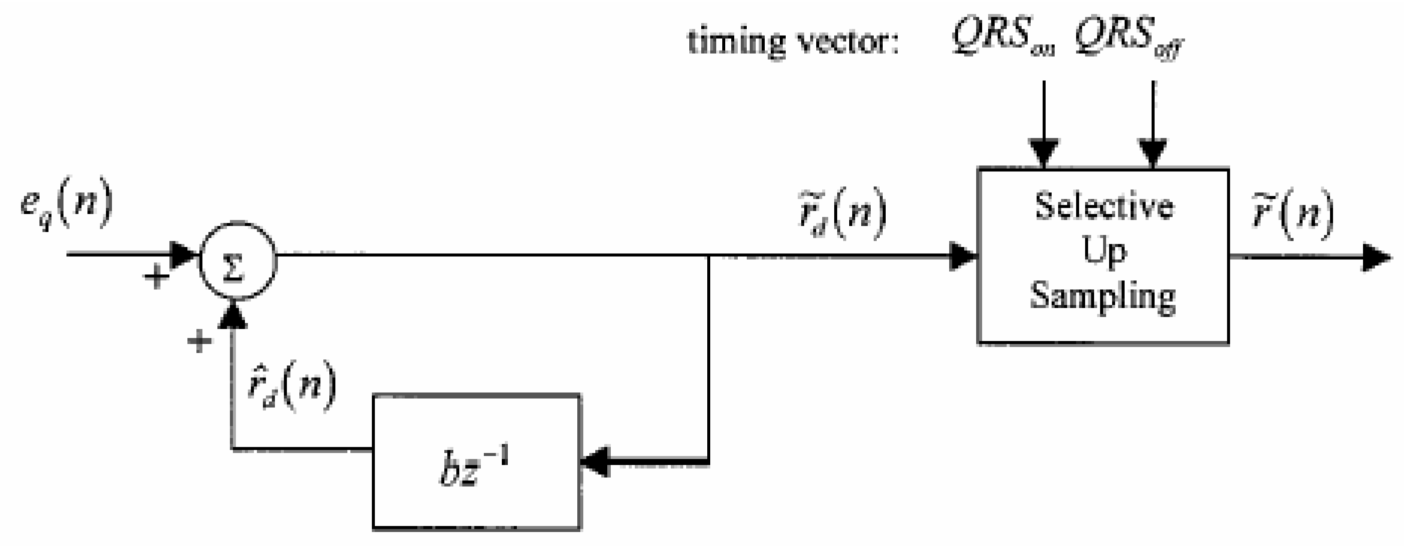


# The compression algorithm

- The decoding system



# The compression algorithm



# The compression algorithm

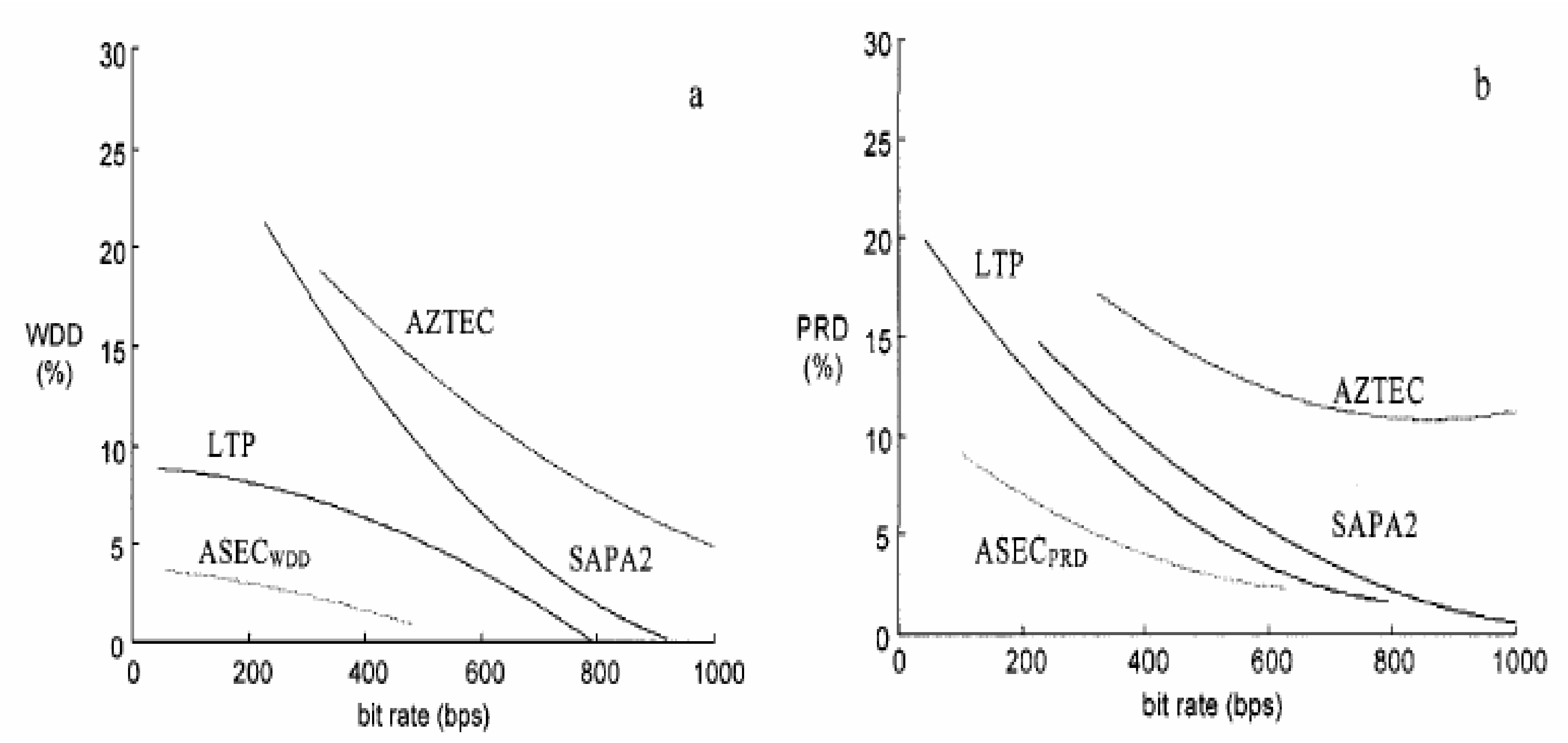
TABLE I
THE BIT ALLOCATION

| Parameter | | | No. of Bits | Remarks |
|---|---|---|---|---|
| # | Name | Sign / partition | | |
| 1 | Number of Quantizer levels & Complex Type | $Q_N$ | 7 | Coded no. of Q levels for each section (P, QRS, T) |
| 2 | Beat Code Word | $index(CW)$ | 3 | Codebook size is 8 |
| 3 | LTP Coefficients | $index(\mathbf{a}_q)$ | 6 | The index of the LTP vector |
| 4 | Timing Vector (L) | $RR_{int}$ | 8 | No. of samples: $(R - R)$ |
| | | $Beat_{off}$ | 6 | $(Beat_{off} - R)$ |
| | | $QRS_{on}$ | 5 | $(R - QRS_{on})$ |
| | | $QRS_{off}$ | 5 | $(QRS_{off} - R)$ |
| 5 | Quantizer's Ranges | $P_{section}$ | 16 | Transmitted if $Q_P \neq 0$ |
| | | $QRS_{section}$ | 16 | Transmitted if $Q_{QRS} \neq 0$ |
| | | $T_{section}$ | 16 | Transmitted if $Q_T \neq 0$ |
| 6 | Residuals | $e_q(n)$ | 0-4 | (per sample) |
| | **Total Range** (bits per beat) | | 40 - 1848 | see remarks in the text |
| | **Total Range** (bits per second) | | 40 - 2696 | (CR = 75:1 – 1.11:1) |

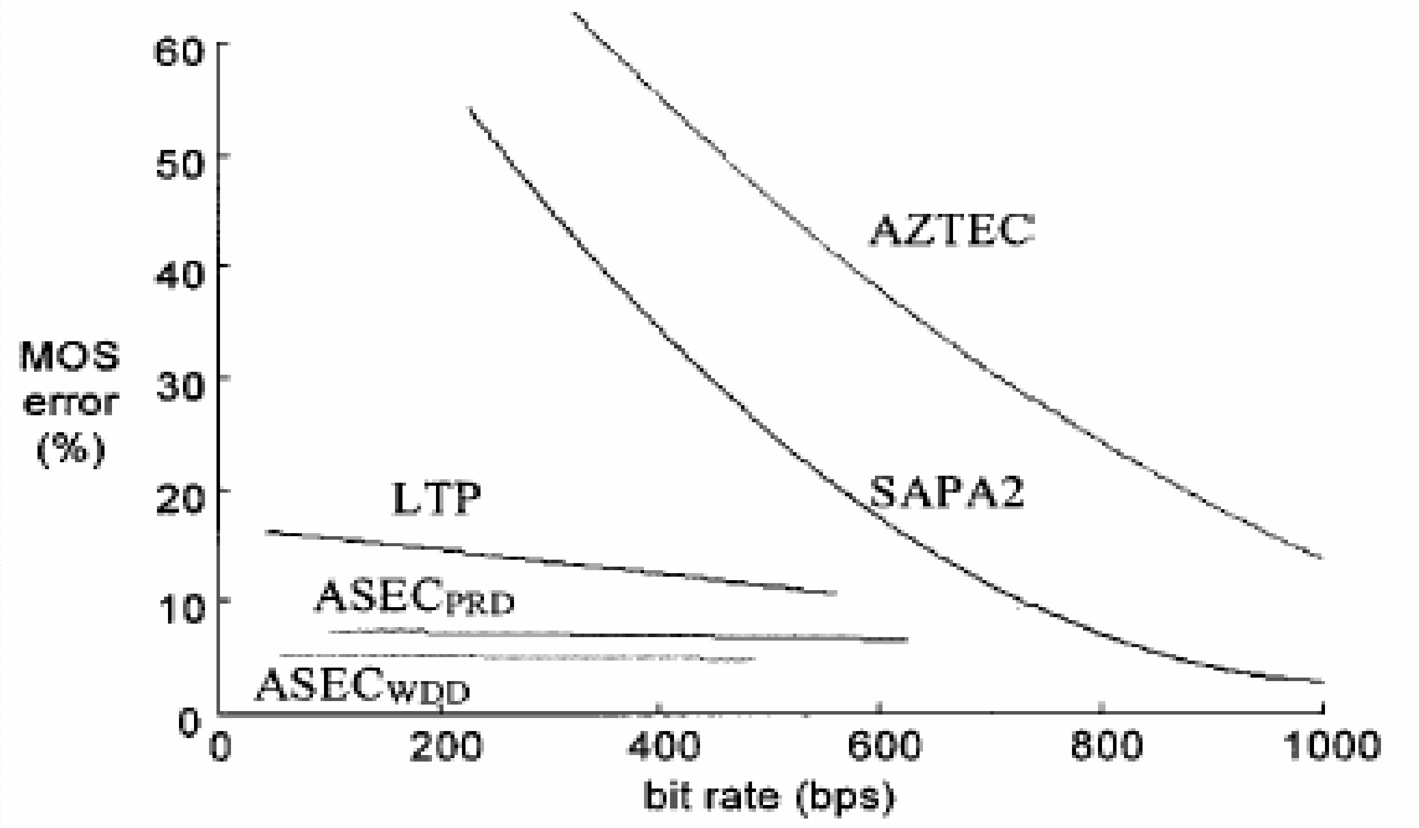
# Results and discussion

- A mean compression rate of approximately 100 bit/sec (compression ratio of about 30:1) has been achieveed with a good reconstructed signal quality (WDD below 4% and PRD below 8%)

# Results and discussion



# Results and discussion



# Reference


- S. M. S. Jalaleddine, C. G. Hutchens, R. D. Strattan, W. A. Coberly "ECG Data Compression Techniques-A Unified Approach," IEEE, Trans. on Biomedical Engineering. Vol. 37, NO. 4, APRIL 1990
- G. Nave, A. Cohen "ECG Compression Using Long-Term Prediction," IEEE, Trans. On Biomedical Engineering, Vol. 40, NO. 9, Sept. 1993
- Y. Zigel ,A. Cohen, and A, Katz "ECG Signal Compression Using Analysis by Synthesis Coding," IEEE Trans. Biomed. Vol. 47, NO. 10, OCT. 2000
- Y. Zigel ,A. Cohen, and A, Katz "The Weighted Diagnostic Distrotion (WDD) Measure for ECG Signal Compression," IEEE Trans. Biomed. Vol. 47, NO. 11, NOV. 2001
- 戴顯權"資料壓縮"

# An Efficient Coding Algorithm for the Compression of ECG Signals Using the Wavelet Transform

B. A. Rajoub, "An Efficient Coding Algorithm for the Compression of ECG signals Using the Wavelet Transform," IEEE Trans. Biomed. Vol. 49, NO. 4, APRIL 2002

# Outline

- Introduction
- Wavelet Transform
- Compression Algorithm
  - Preprocessing
  - DWT and Thresholding
  - Coding the Wavelet Coefficients
  - Header Information
  - Performance Measure

# Outline

- Experimental Results
- Conclusion

# Introduction

- **The compression of ECG signals**

1. Dedicated Techniques
   - Heuristic algorithm : AZTEC, TP, FAN, SAPA, SLOPE, etc.
   - Optimization algorithm : LTP, ASEC, etc.
2. General Techniques
   - DPCM, SC, TC, VQ, etc.

# Wavelet Transform

- Continuous wavelet transform

$$W(s,\tau)=\frac{1}{\sqrt{s}}\int f(t)\psi^{*}\left(\frac{t-\tau}{s}\right)dt$$

$$f(t)=\int\int W(s,\tau)\psi_{s,\tau}(t)d\tau ds$$

- Where $\psi$ is a fundamental waveform called a mother wavelet

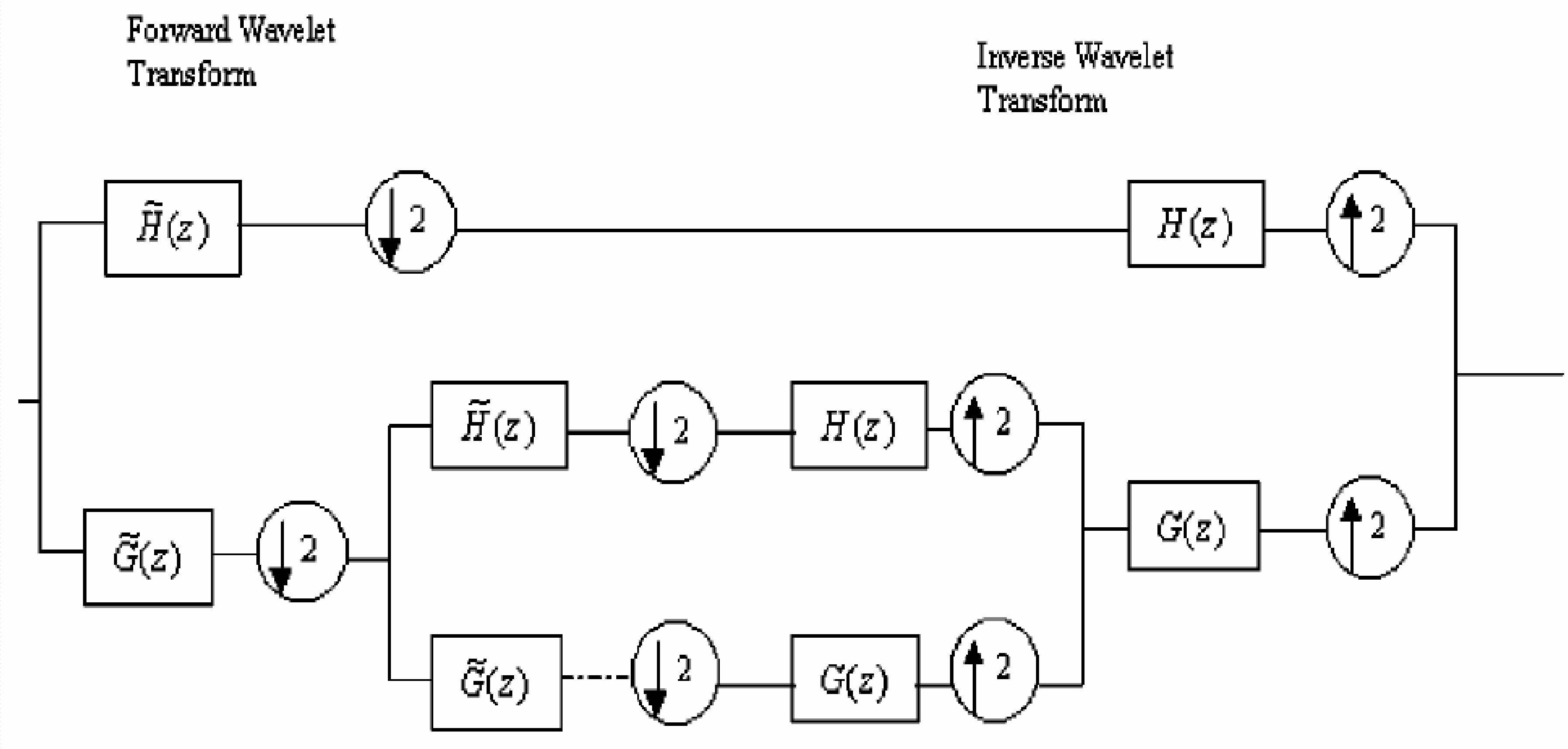
# Wavelet Transform

- Discrete wavelet transform

$$\psi_{j,k}(t) = \frac{1}{\sqrt{s_0^j}} \psi\left( \frac{t - k\tau_0 s_0^j}{s_0^j} \right), \quad j,k \in Z$$

- The wavelet transform can be implemented efficiently using SC as tree-structured, perfect-reconstruction filter banks

# Wavelet Transform



# Compression Algorithm

- Preprocessing
  - Normalization, mean removal, zero padding

$$y_i = \left[ zeros(1, M) \left( \frac{x_i}{Am} \right) - m_x zeros(1, M) \right]$$

$$m_x = mean\left( \frac{x_i}{Am} \right)$$

# Compression Algorithm

- DWT and Thresholding
  - Fifth level DWT using the BiorSpline (bior4.4) wavelet
  - Thresholding : eliminating all coefficients that are smaller than a threshold T
  - The threshold values were selected based on the EPE

$$EPE_{D_i} = \frac{\overline{E}_{CD_i}}{E_{CD_i}} \times 100\%$$

# Compression Algorithm

EPE VALUES FOR THE DECOMPOSITION SUBBANDS

| Energy packing efficiency (%) | |
|---|---|
| $EPE_{D1}$ | 0.0151 |
| $EPE_{D2}$ | 0.0276 |
| $EPE_{D3}$ | 0.0200 |
| $EPE_{D4}$ | 0.1386 |
| $EPE_{D5}$ | 0.2181 |
| $EPE_{A5}$ | 99.5806 |

# Compression Algorithm

- DWT and Thresholding
  - After thresholding, the decomposition coefficients are grouped in one vector
  - Where

$$dec = \left[ \overline{C}_{A_5} \quad \overline{C}_{D_5} \quad \overline{C}_{D_4 - D_1} \right]$$

$$\overline{C}_{D_4 - D_1} = \left[ C_{D_4} \quad C_{D_3} \quad C_{D_2} \quad C_{D_1} \right]$$

  - Setting EPE = 99.9%

# Compression Algorithm

- DWT and Thresholding
  1. Calculate the total energy E in the wavelet coefficients X :

     $$E = \sum X^2$$

  2. Calculate the desired retained energy $E'$ , in the threshold coefficients:

     $$E' = 0.999 E$$

# Compression Algorithm

3. Form the sequence $X_x[k]$ by sorting the magnitudes of the wavelet coefficients in descending order.

4. set energy= 0 ; set k= 0

   while energy < $E'$

   k=k+1

   $energy = energy + \left(X_x[k]\right)^2$

   end

   thr = $X_x[k]$

# Compression Algorithm

- Coding the wavelet coefficients
  - Coding the significance map, and coding of the significant coefficients

1. Variable-length code based on run length encoding
   - 1050 symbols => "1" "1011" "10000011010"

2. Encoded by assigning a fixed number of bits
   - -0.09375 => "1" "00011"

# Compression Algorithm

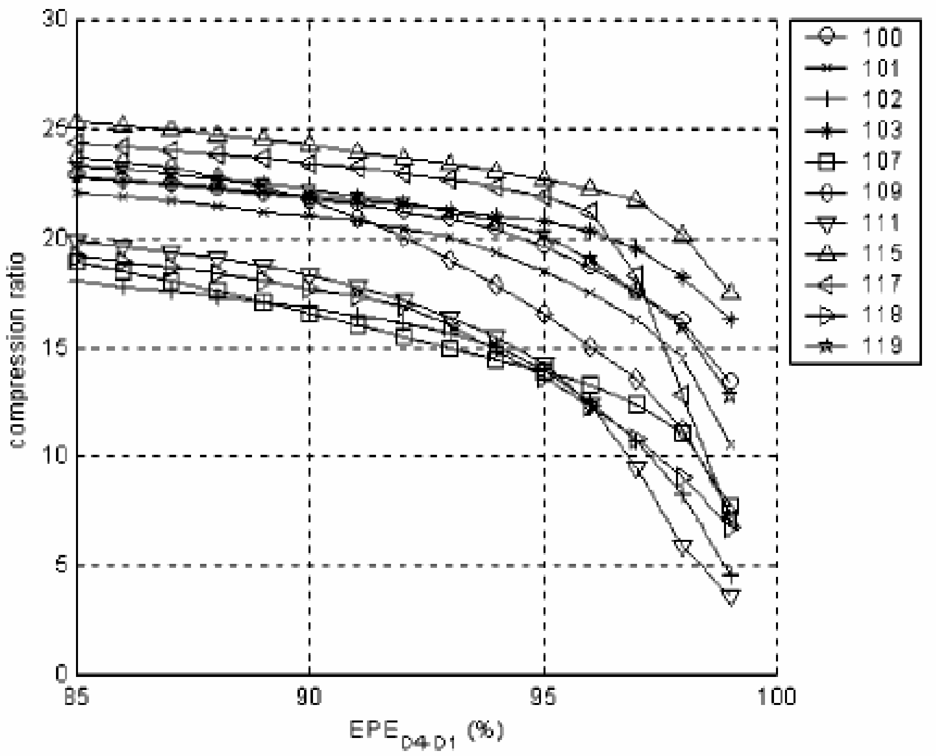
- Header Information
  - First 20 bits : the total number of wavelet coefficients
  - Next 20 bits : the index value of the last significant coefficient
  - Next 12 bits : the maximum magnitude of the original signal
  - Last 12 bits : the mean of the normalized signal

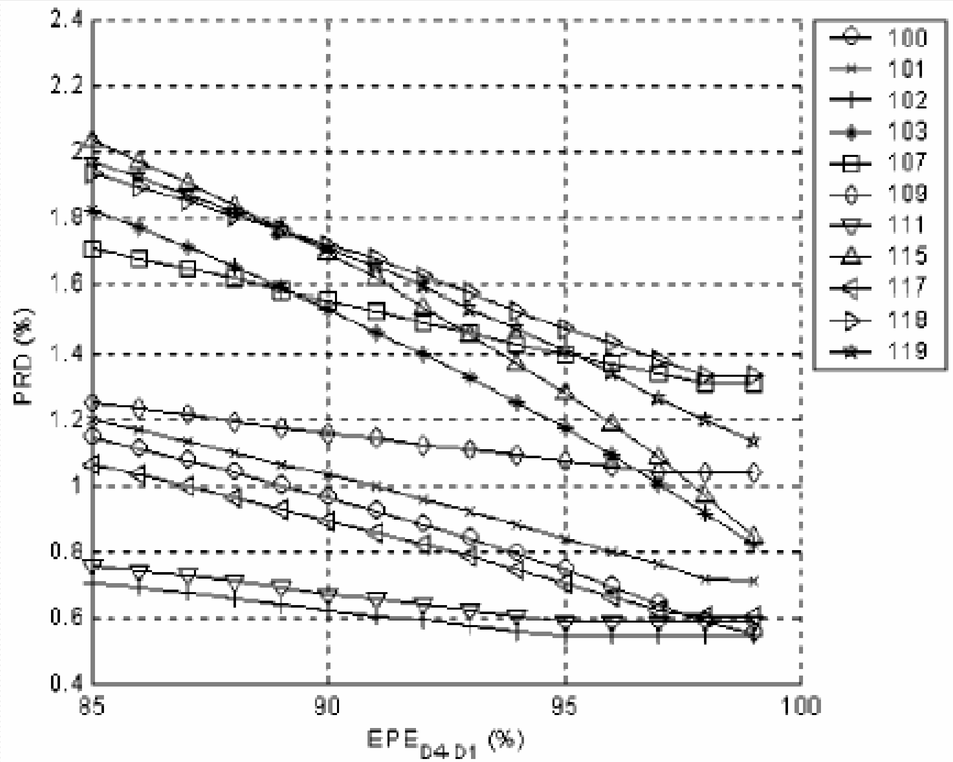
# Compression Algorithm

- Performance measure
  - Compression ratio : $CR = \dfrac{N_x}{H + N_s + N_v}$
  - Reconstructed signal : $\bar{x}_i = (y_i + m_x) \times A_m$

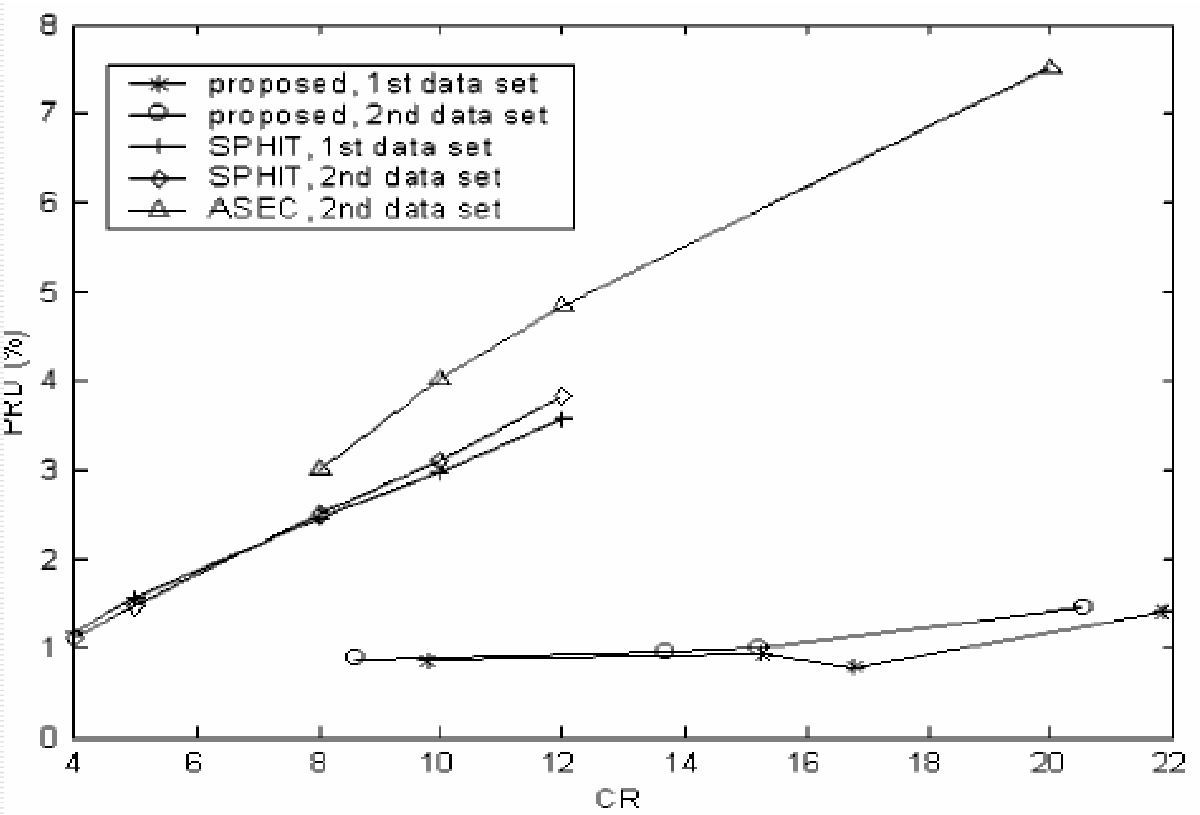
$$PRD = \sqrt{\frac{\sum_{1}^{n_x} (x_i - \bar{x}_i)^2}{\sum_{1}^{n_x} (x_i)^2}} \times 100$$

# Experimental Results



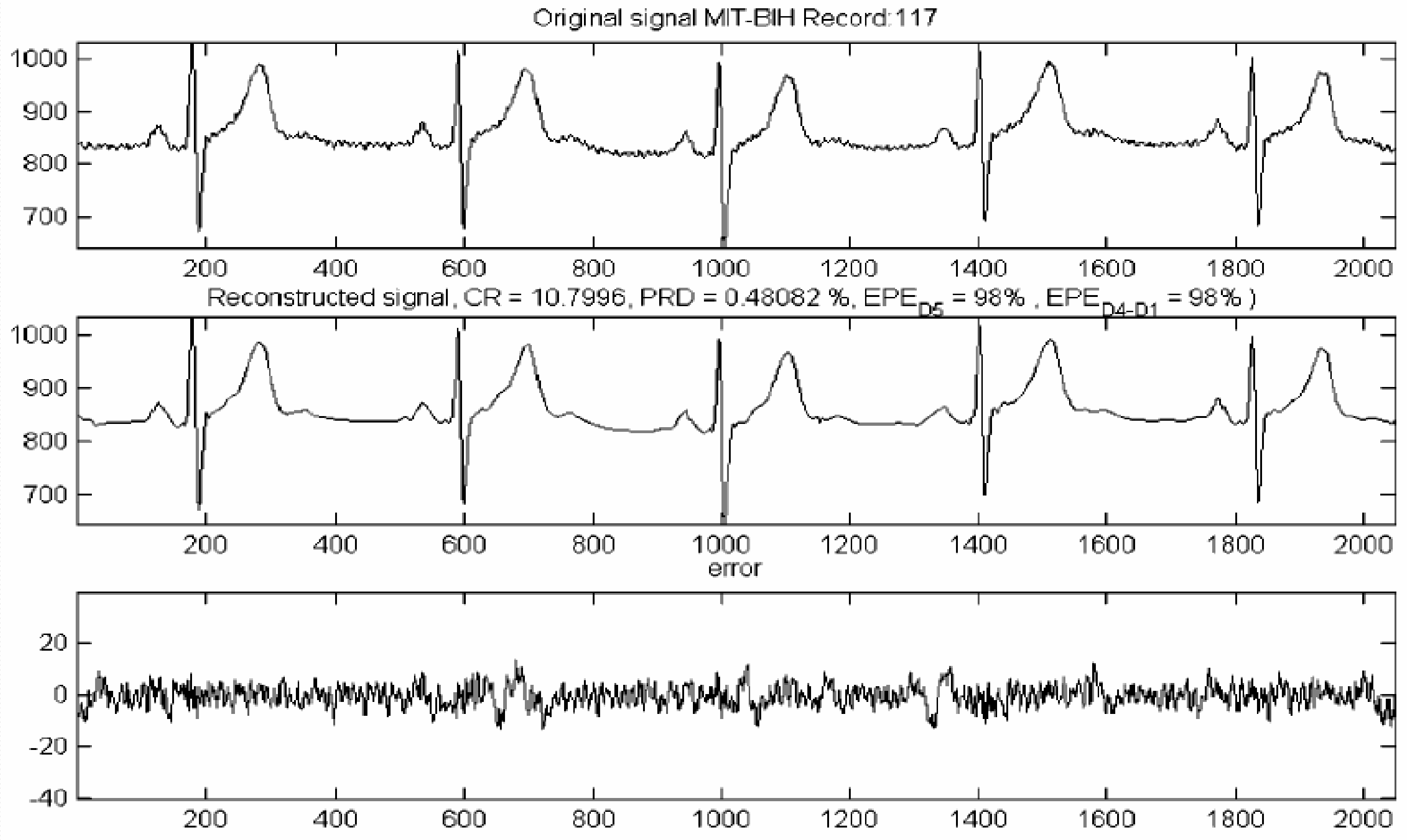
# Experimental Results



# Experimental Results

| Algorithm | PRD (%) | CR | Signal | Sampling frequency (Hz) | Resolution bit/sample |
|---|---|---|---|---|---|
| Proposed | 1.06% | 22.19:1 | 117 | 360 Hz | 11 |
| Proposed | 1.95% | 23:1 | 119 | 360 Hz | 11 |
| SPHIT | 1.18% | 8:1 | 117 | 360 Hz | 11 |
| Hilton | 2.6% | 8:1 | 117 | 360 Hz | 11 |
| Djohn | 3.9% | 8:1 | 117 | 360 Hz | 11 |
| ASEC | 5.5% | 21.6:1 | 119 | 360 Hz | 11 |

# Experimental Results



# Conclusion

- A wavelet-based ECG data compression is better than the others used for comparison.

- The high efficiency, high speed and simplicity make the algorithm an attractive choice for use in portable heart monitoring systems.

# Reference


- B. A. Rajoub, “An Efficient Coding Algorithm for the Compression of ECG signals Using the Wavelet Transform,” IEEE Trans. Biomed. Vol. 49, NO. 4, APRIL 2002
- A. Alshamali, and A. S. AL=Fahoum ,“Comments on “An Efficient Coding Algorithm for the Compression of ECG signals Using the Wavelet Transform”,” IEEE Trans. Biomed. Vol. 50, NO. 8, AUG 2003

# A New 3-D Display Method for 12-Lead ECG

Huihua Kenny Chiang, *Member*, *IEEE*, Chao-Wei Chu, Gau-Yang Chen, and Cheng-Deng Kuo*,

*IEEE Trans*. on Biomedical Engineering, Vol. 48, No. 10, Oct. 2001, p.p. 1195-1202

# Outline

- Abstract
- Keywords
- Motive
- Introduction
- Methods
- Results
- Conclusion

# Abstract

- A new 3-D 12-lead ECG display method is presented which employs a **3-D rectangular coordinate system** to display the 12-lead cardiac electric signals in two 3-D graphs. The 3-D graph consists of a **temporal** axis representing the time domain of the cardiac signals, a **spatial** axis representing the lead positions, and an **amplitude** axis representing the voltages of the cardiac signals. The six **horizontal plane** leads and the other six **frontal plane** leads were displayed in two 3-D graphs, respectively.

# Abstract (Cont'd)

- The voltages of the cardiac signals were represented in **rainbow-like** colors.
- **Cubic interpolation** was employed to insert interconnecting points between neighboring leads on each plane and to **smooth** the surface of the 3-D ECG graphs.

# Keywords

- Cardiac Signals
- Three-Dimensional Display Method
- 12-Lead ECG

# Motive

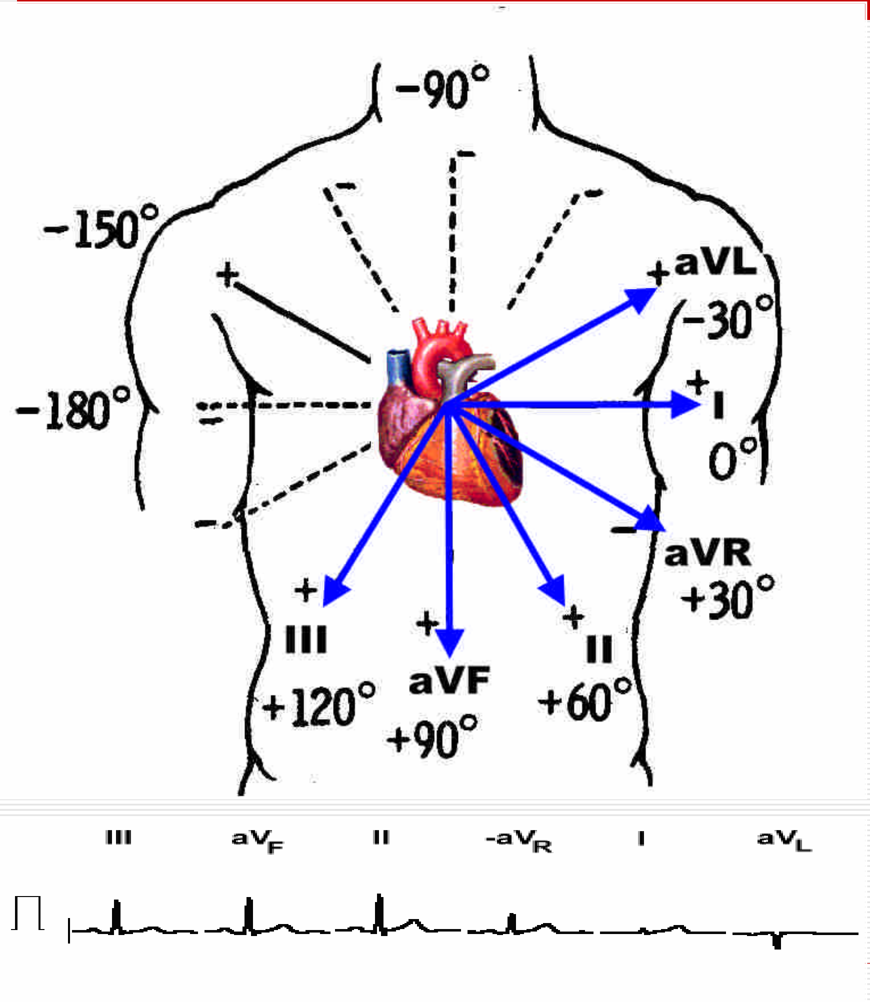
- Physicians need to scan the 12 leads for abnormal features and then try to locate the lesion from the abnormal electrical activity of the heart. This traditional way of examining the standard 12-lead ECG and locating the lesion in the heart is often **laborious**, **time-consuming** and **inefficient**.

# Introduction

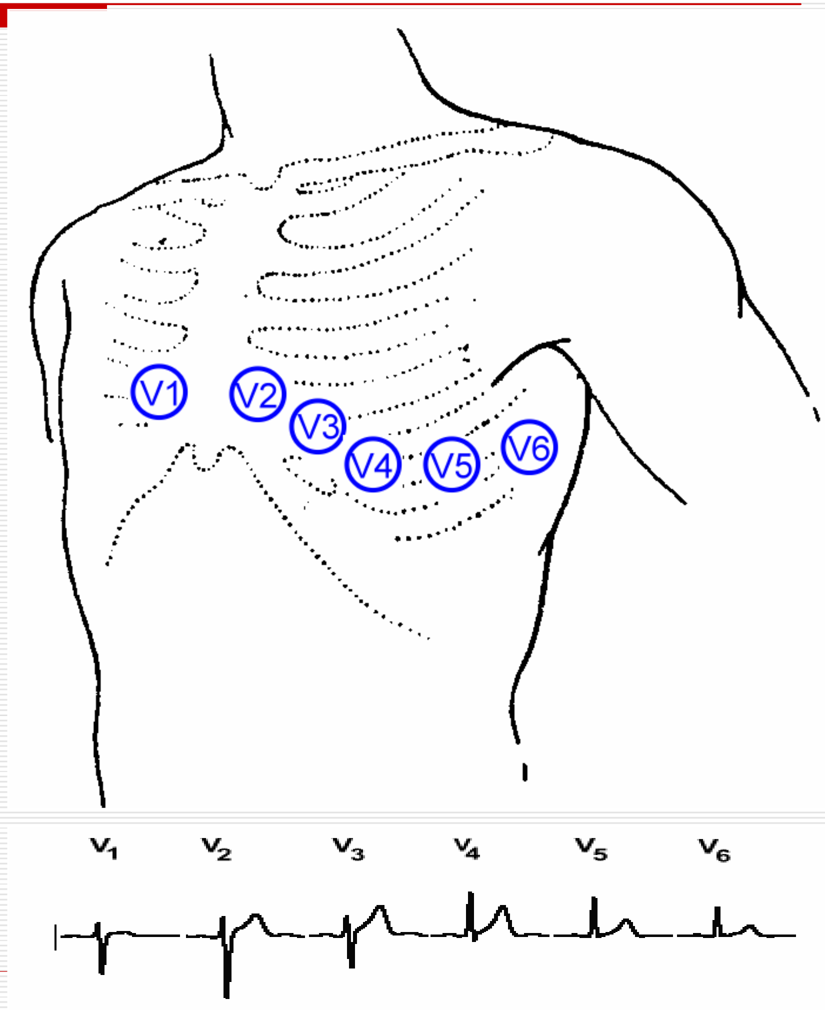
- **Electrocardiogram** (ECG) is one of the most widely used **noninvasive** diagnostic tools for **cardiopulmonary** diseases in clinical medicine. ECG has become an important tool for the **assessment** of the cardiopulmonary condition of the patients.

# Frontal Plane

(郭正典序列、逆 Cabrera 序列)

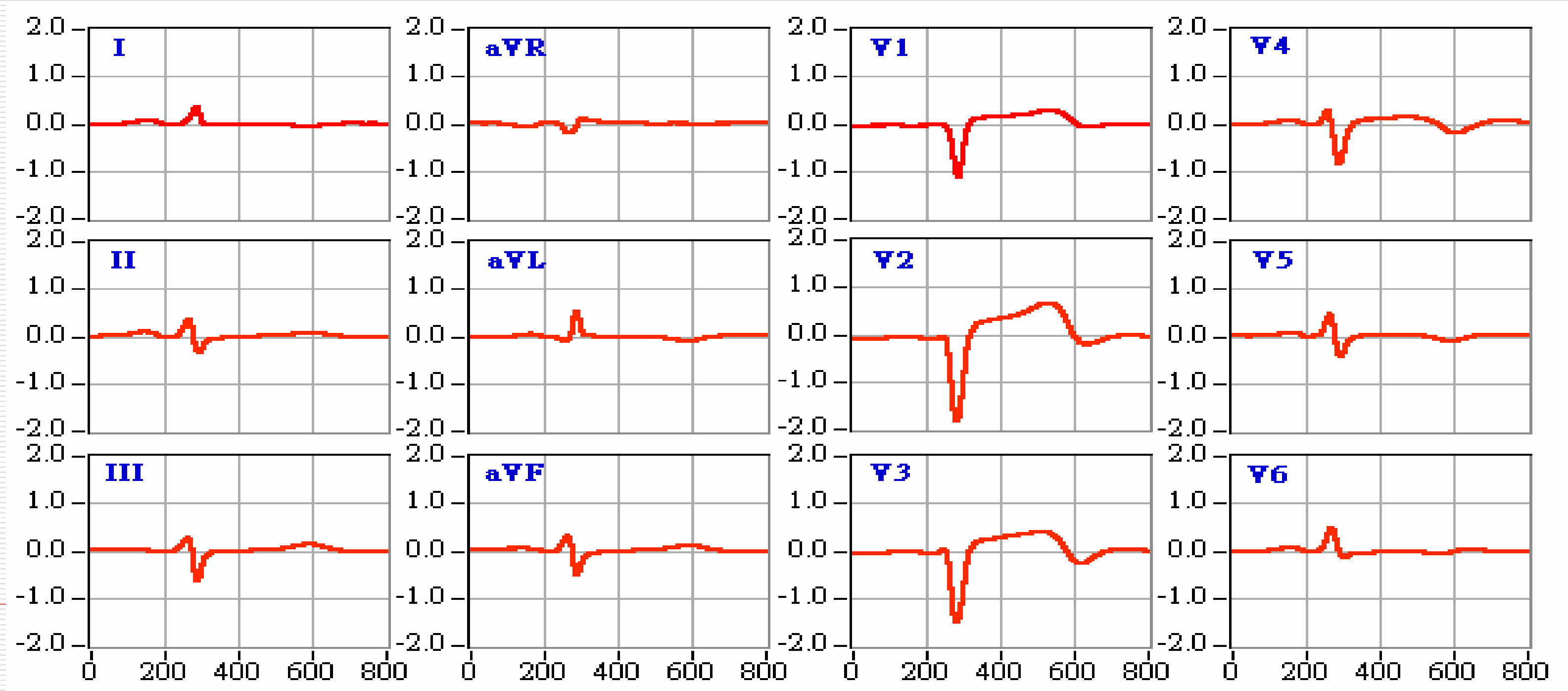


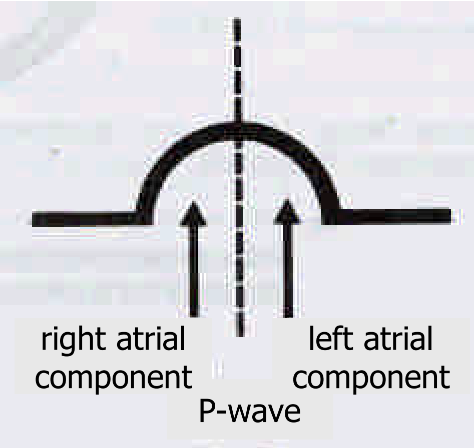

# Horizontal Plane



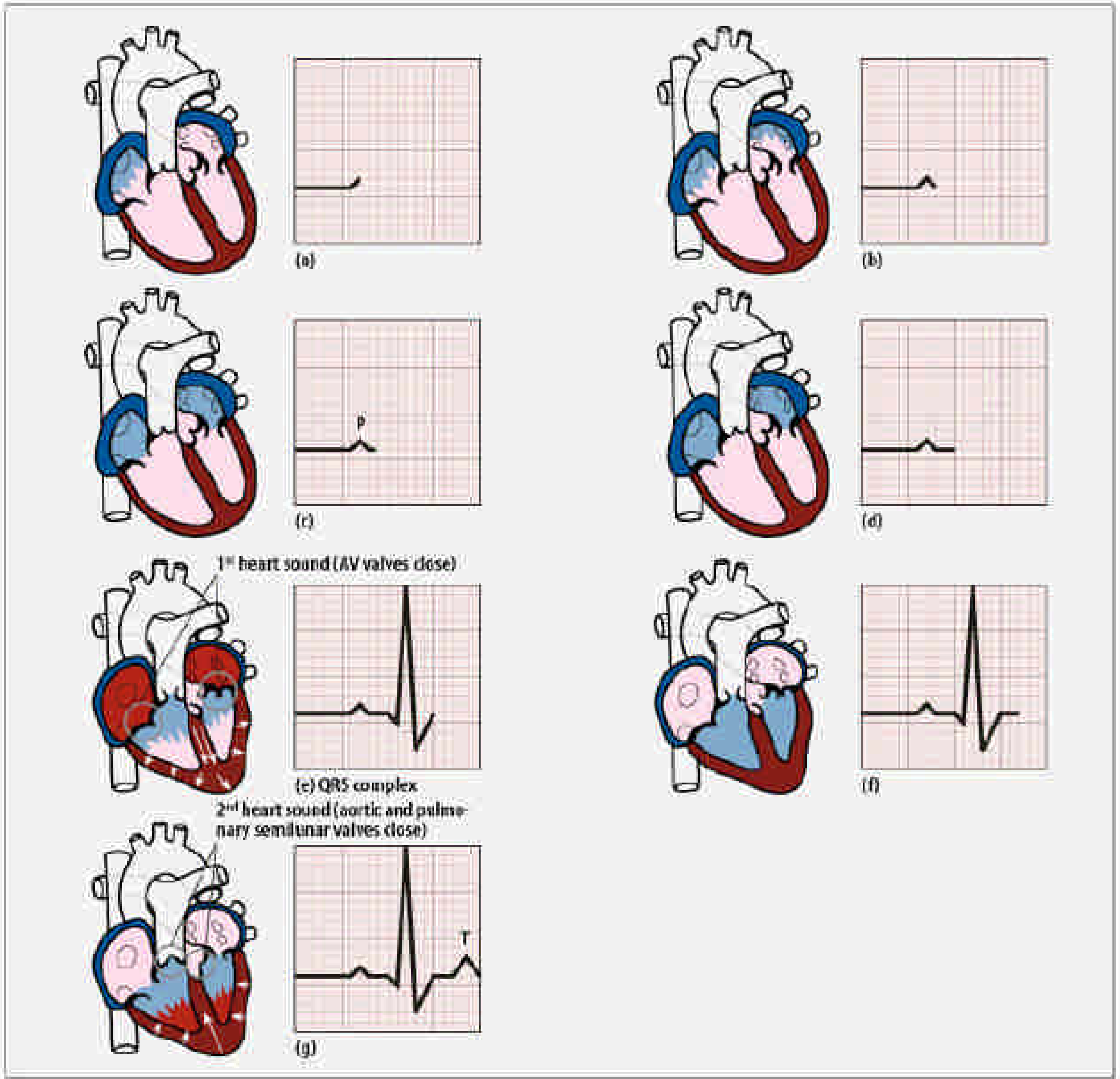
# Standard 12-Lead ECG

- Horizontal Plane : $V_1$, $V_2$, $V_3$, $V_4$, $V_5$, $V_6$
- Frontal Plane : I, II, III, $aV_R$, $aV_L$, $aV_F$





right atrial component
left atrial component
P-wave

(a)
(b)
P
(c)
(d)
1st heart sound (AV valves close)
(e) QRS complex
(f)
2nd heart sound (aortic and pulmonary semilunar valves close)
T
(g)

# Traditional Limitation

- Number of leads need to be **evaluated sequentially** to assess the change in the electric signals relating to cardiopulmonary abnormality.
- Lacks the ability in offering integral information about the **spatial distribution** of the electrical activity of the heart to the physicians, especially the cardiac signals on the **frontal plane**.

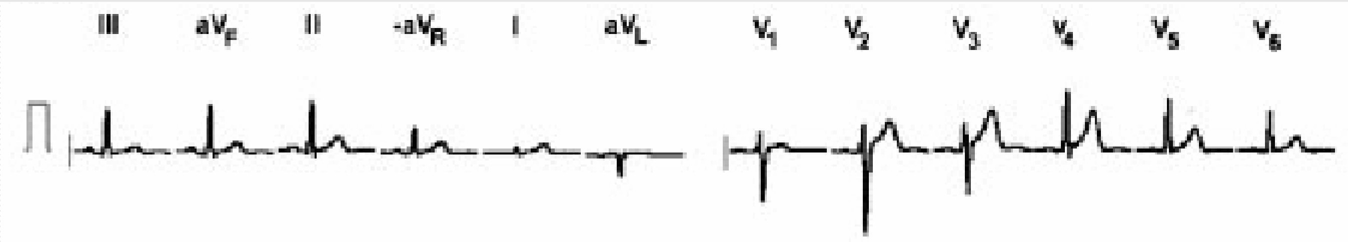
# Development of Cardiogram

- 1901, invented ECG by Einthoven
  - Electro-Cardiogram
- 1920, invented VCG by Hubert Mann
  - Vector-Cardiogram
- 1922, invented BSPM by Cohen and He
  - Body Surface Potential Maps
- 1997, invented 3D-ECG by Kuo and Chiang
  - Perspective View, Bird’s Eye View

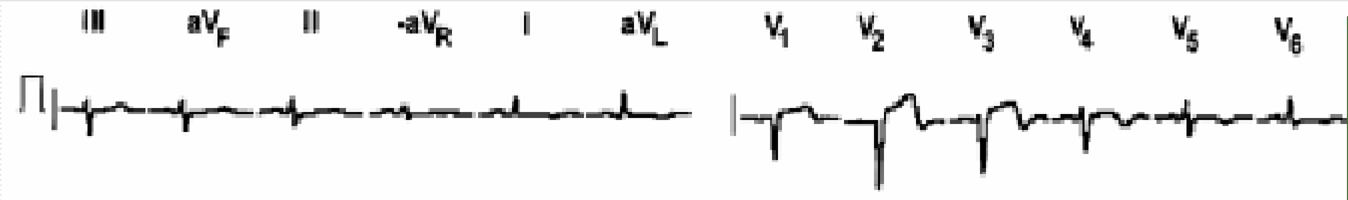
# Patent

- 郭正典、江惠華、陳志瑋。心電訊號以三維圖形顯示的方法。
  - 中華民國專利發明第087171號。
  - 專利期間1997/06至2016/12.
- Cheng-Deng Kuo, Huihua Kenny Chiang. Three-dimensional electrocardiogram display method.
  - *U.S. patent* No. 5,782,773, July 21, 1998.
  - From 1997/05 to 2017/12.

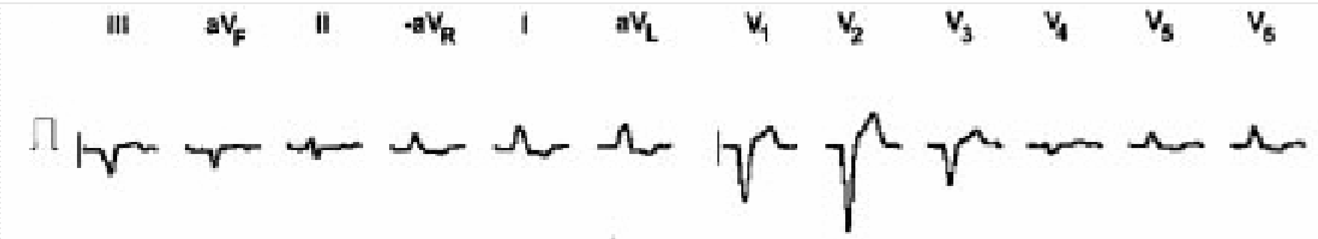
# The Conventional 12 Line Segments of 12-Lead ECG




① Normal Subject




② Anterior wall myocardial infarction
心室前壁梗塞




③ Left Bundle-Branch Block (LBBB)
左束枝傳導阻滯

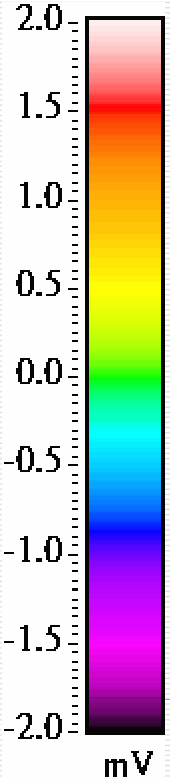
# Method of 3D ECG

1. 12-Lead ECG Measurements
2. Three-Dimensional Coordinate System
3. Amplitude-to-Color Mapping
4. Volume Conductor and Interpolation
5. Three-Dimensional Display Format
6. Clinical Evaluation of the New Method

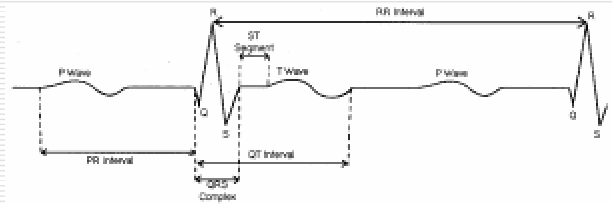
# 12-Lead ECG Measurement

1. PC-ECG 1200M (Norav Medical, Kiryat Bialik, Israel)
2. Measured six horizontal plane chest leads
   - V1, V2, V3 ,V4 ,V5 ,V6
3. Measured two frontal plane limb leads
   - I, II
4. The cardiac signals were transmitted to a personal computer through a standard RS-232 interface for signal processing and 3-D display.
5. The other four frontal plane leads were calculated from leads I and II.
6. The 3-D display program was developed by LabVIEW 5.1 software (National Instrument, Austin, TX).

# Amplitude-to-Color Mapping

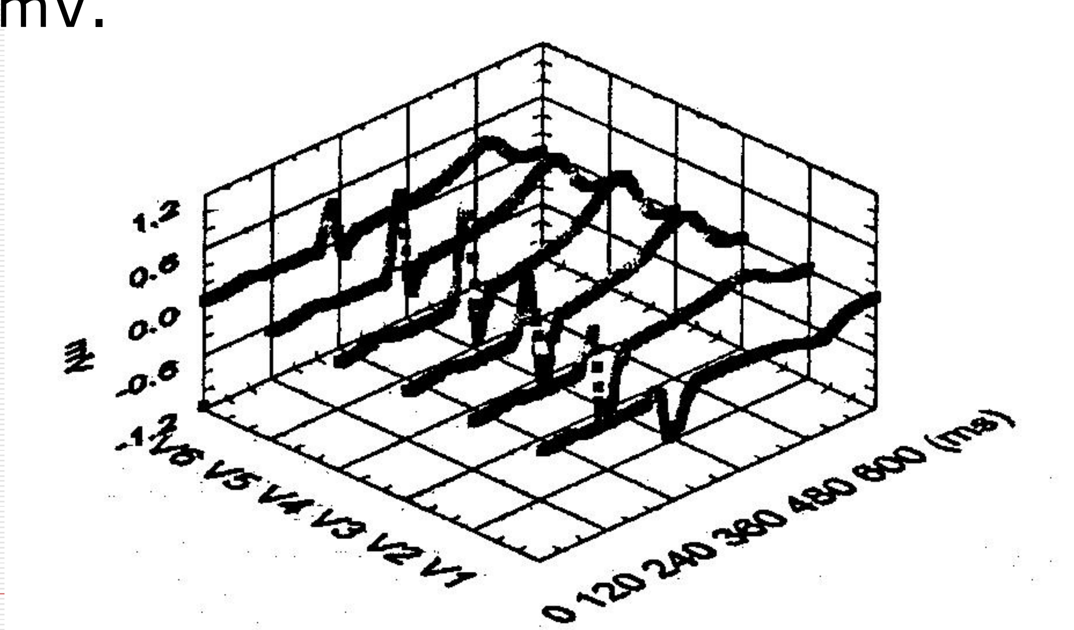



- The voltages of the 12-lead cardiac signals were represented by **rainbow-like** colors according to a predetermined **amplitude-to-color** mapping table.
- The signal strength and the locations of the **P wave, QRS complex,** and **T wave** could be **easily observed** on the two 3-D graphs representing the horizontal and frontal planes, respectively.



# Definition of 3-Axis

- **X-axis** represented the **temporal** evolution of the cardiac signal in milliseconds.
- **Y-axis** represented the **spatial** locations of the leads.
- **Z-axis** represented the **voltages** of the cardiac signals in mV.

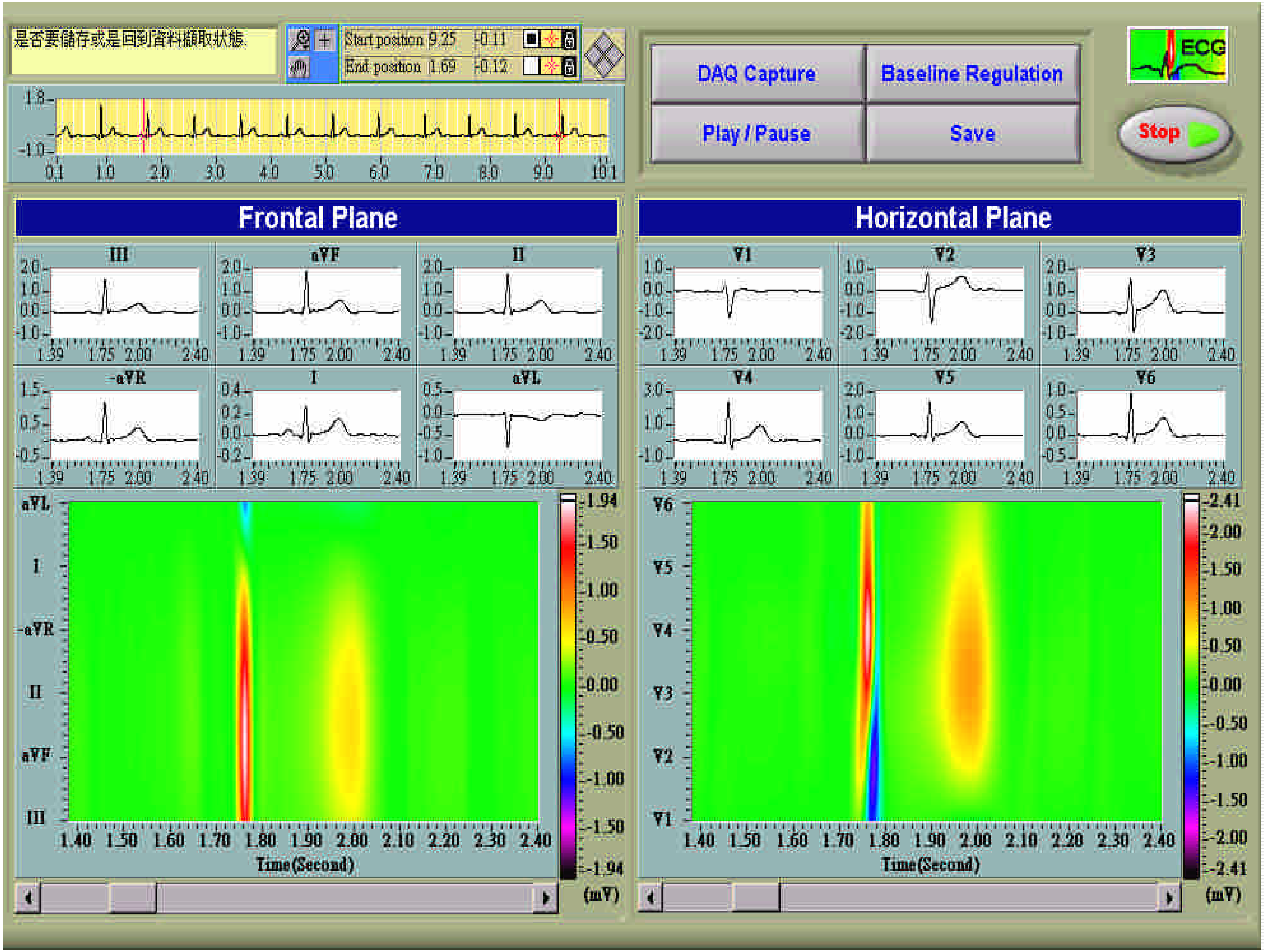


# Volume Conductor and Interpolation

- The human body is full of **body fluid** and **ions**, it can be treated as a **volume conductor** in which electric conductivity is **continuous** and **homogeneous**. Therefore, the electric signals distributed between consecutive conventional leads could be estimated by **interpolation techniques**.

# Smooth the 3-D Graph

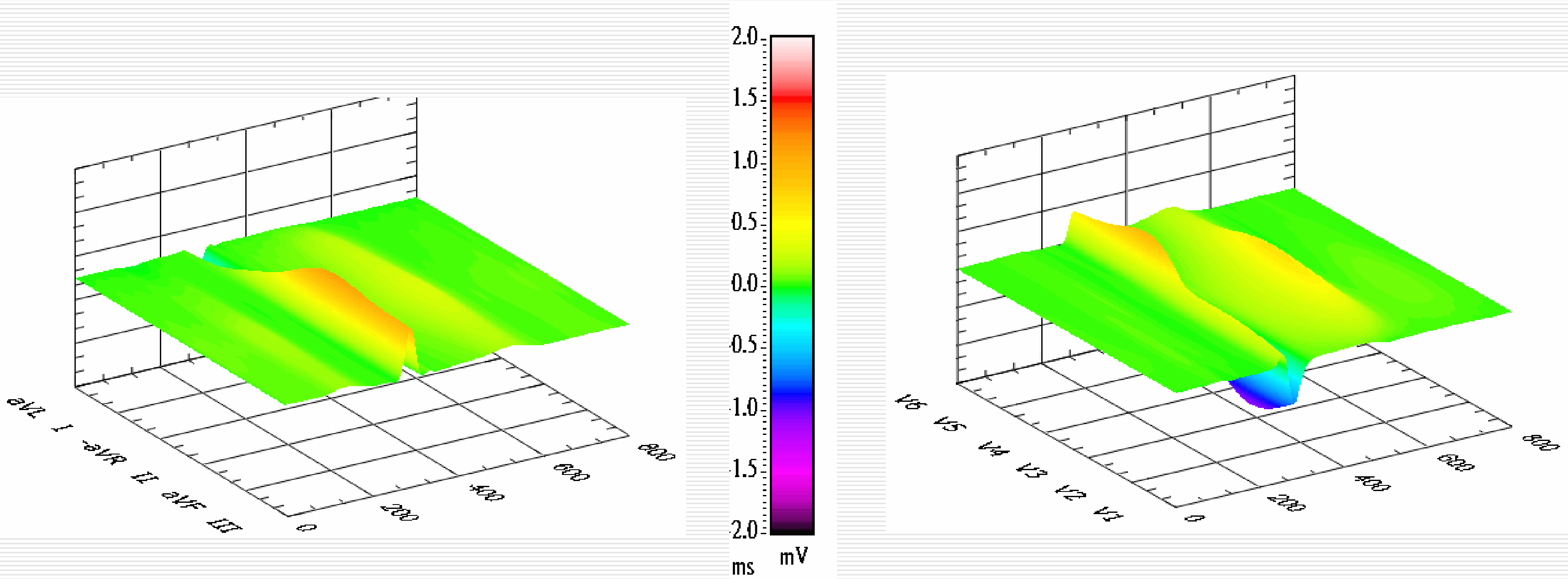
- **Cubic interpolation** between consecutive leads in the spatial axis.
- **29** points were inserted between two successive leads on the **frontal** plane.
- Approximately **1°** phase angle difference between successive points.
- The same **29** points were also inserted between two successive leads on the **horizontal** plane.


是否要儲存或是回到資料擷取狀態
Start position 9.25
End position 1.69
DAQ Capture
Baseline Regulation
Play / Pause
Save
ECG
Stop
Frontal Plane
Horizontal Plane
III
aVF
II
-aVR
I
aVL
V1
V2
V3
V4
V5
V6
Time (Second)
(mV)

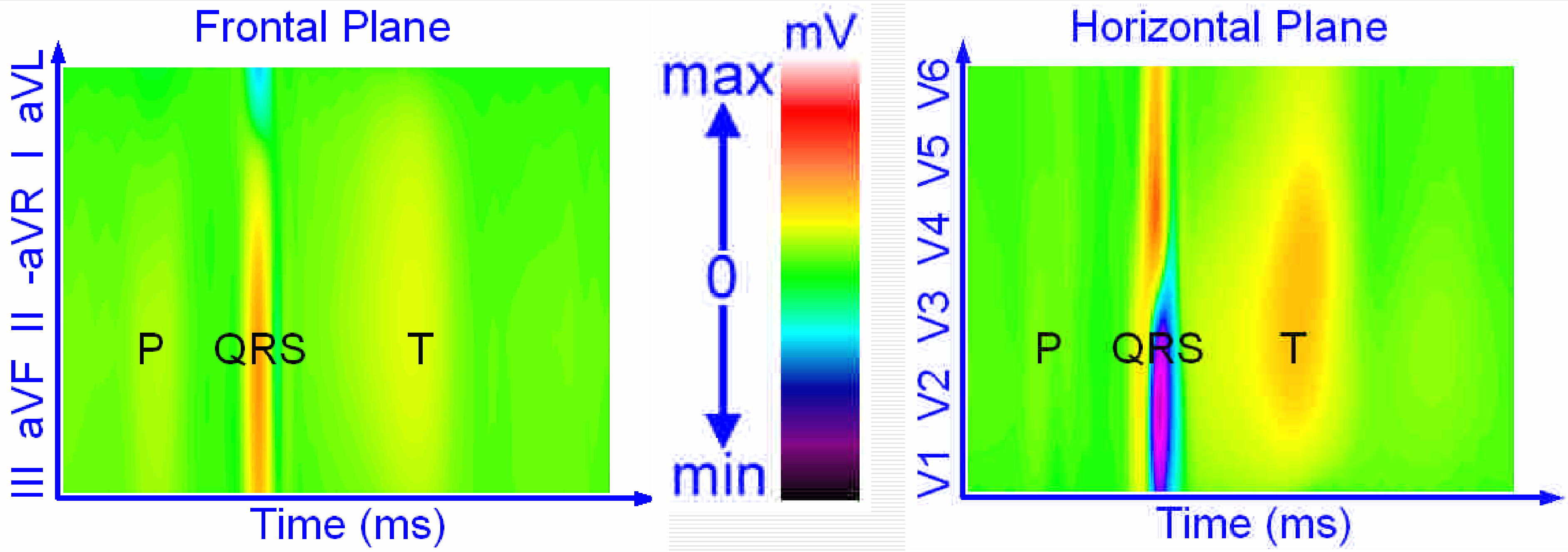
# The Perspective View

3D ECG of **Frontal** Plane

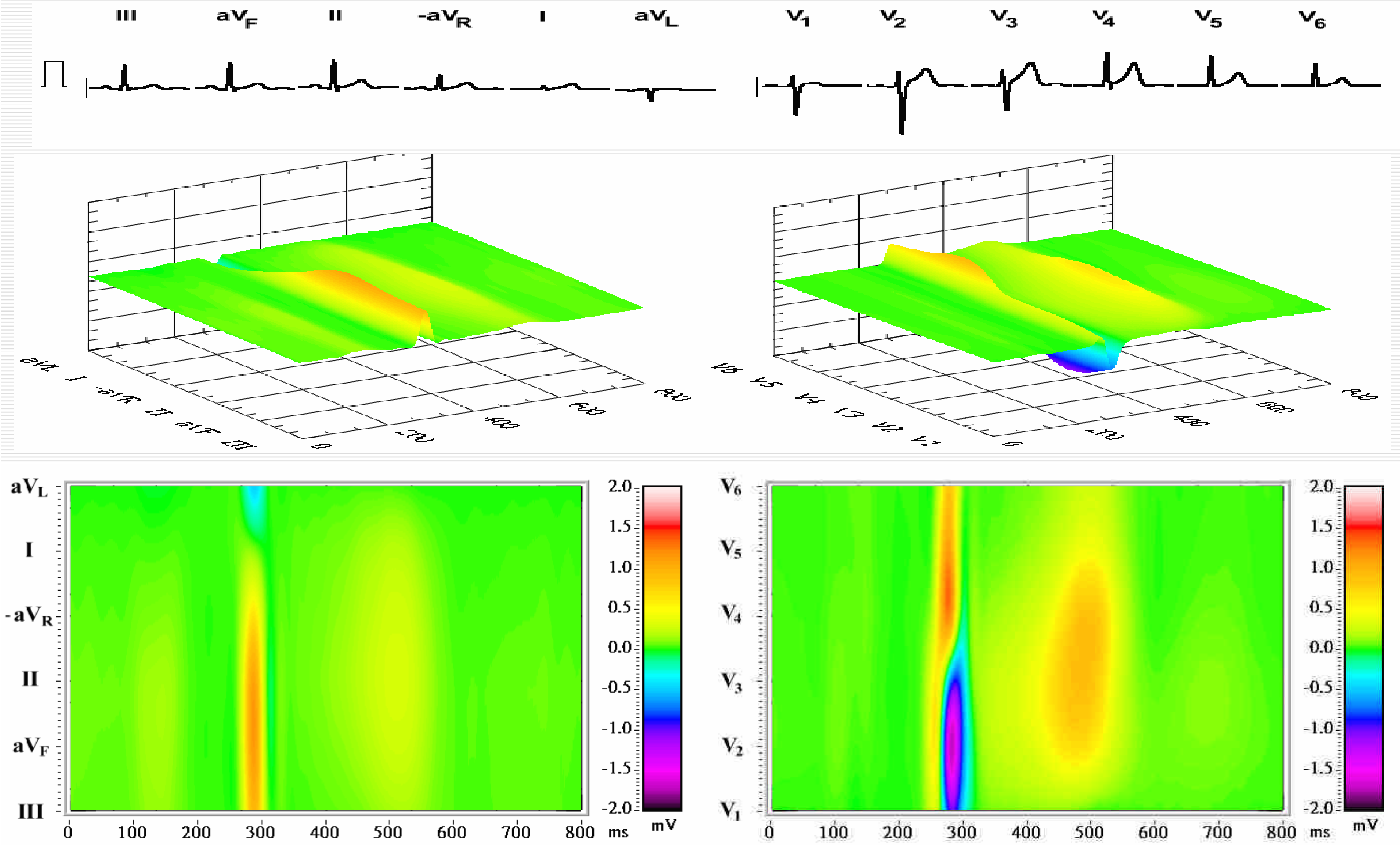
3D ECG of **Horizontal** Plane



# The Bird's Eye View



# Normal Subject (正常人)



# Disease Analysis

- Anterior Wall Myocardial Infarction
  - 心室前壁梗塞
- Left Bundle-Branch Block (LBBB)
  - 左束枝傳導阻滯
- Right Bundle-Branch Block (RBBB)
  - 右束枝傳導阻滯
- Chronic Obstructive Pulmonary Disease (COPD)
  - 慢性阻塞性肺疾

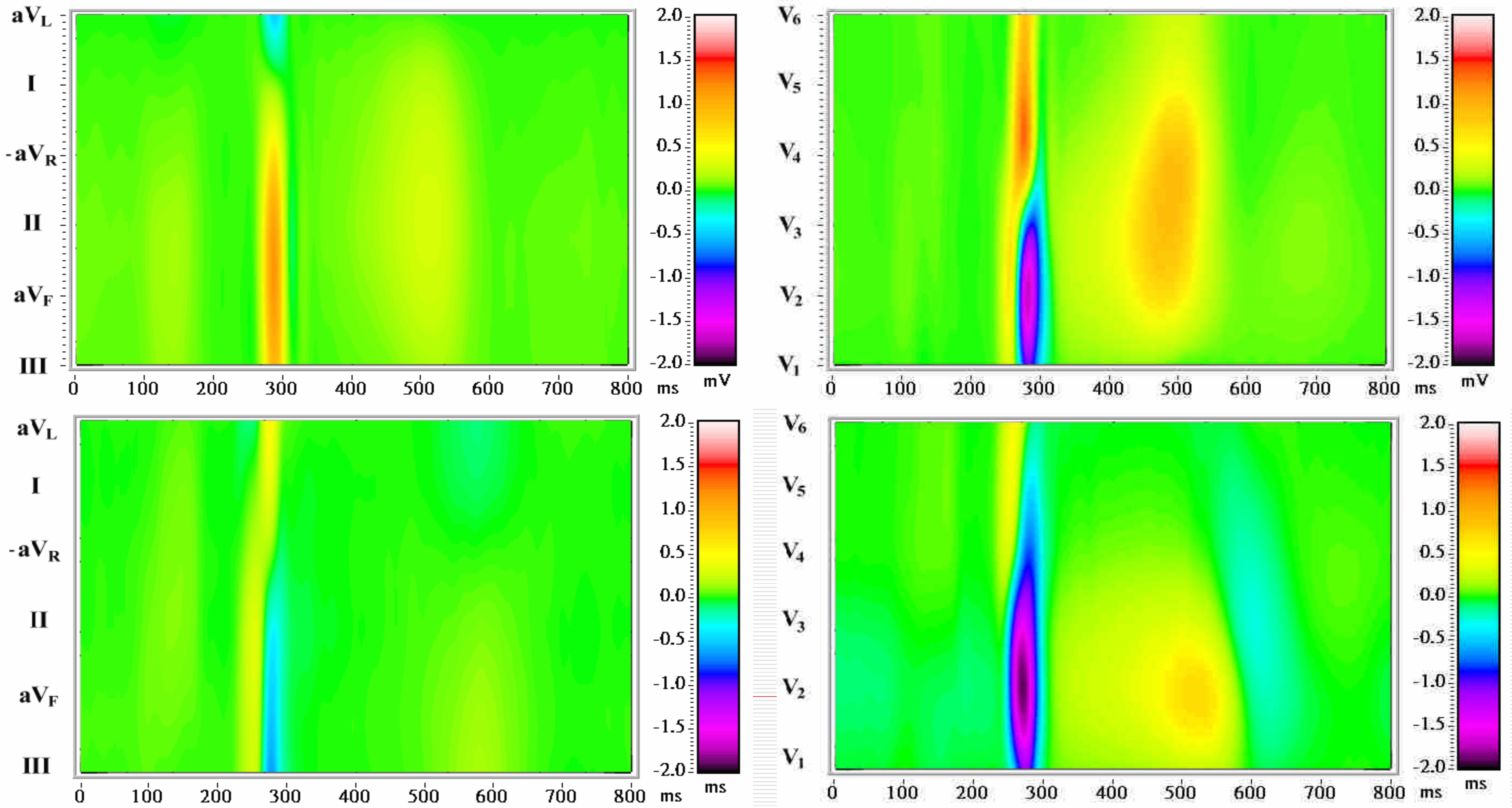
# About COPD

- Emphysema(肺氣腫) and Chronic Bronchitis(慢性支氣管炎) are two major symptoms of COPD. These diseases obstruct the outflow of the respiratory passages and increase work load on the heart. Therefore, COPD is a heart-pulmonary associated disease.

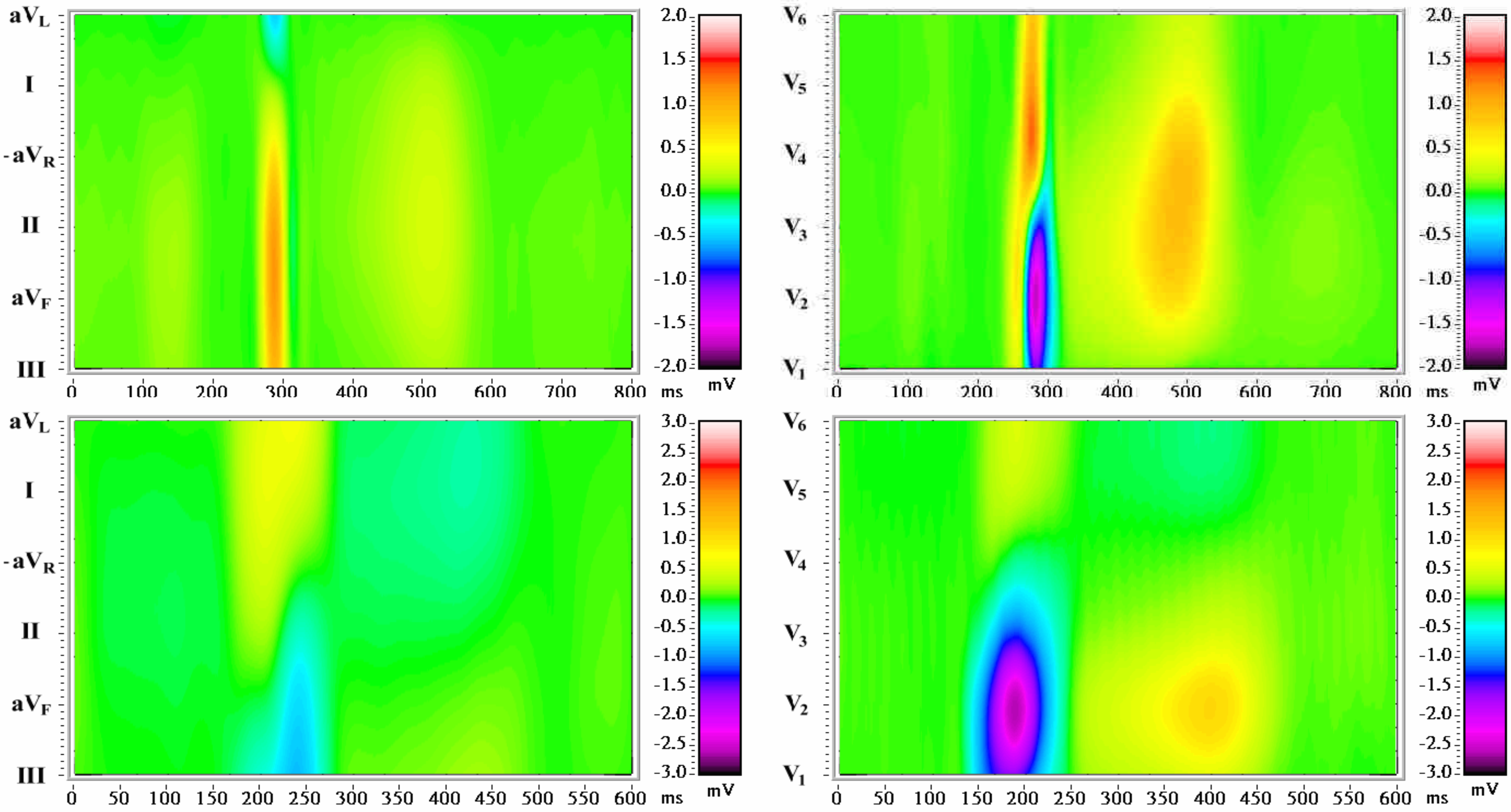
Normal Subject
正常人

*vs.*

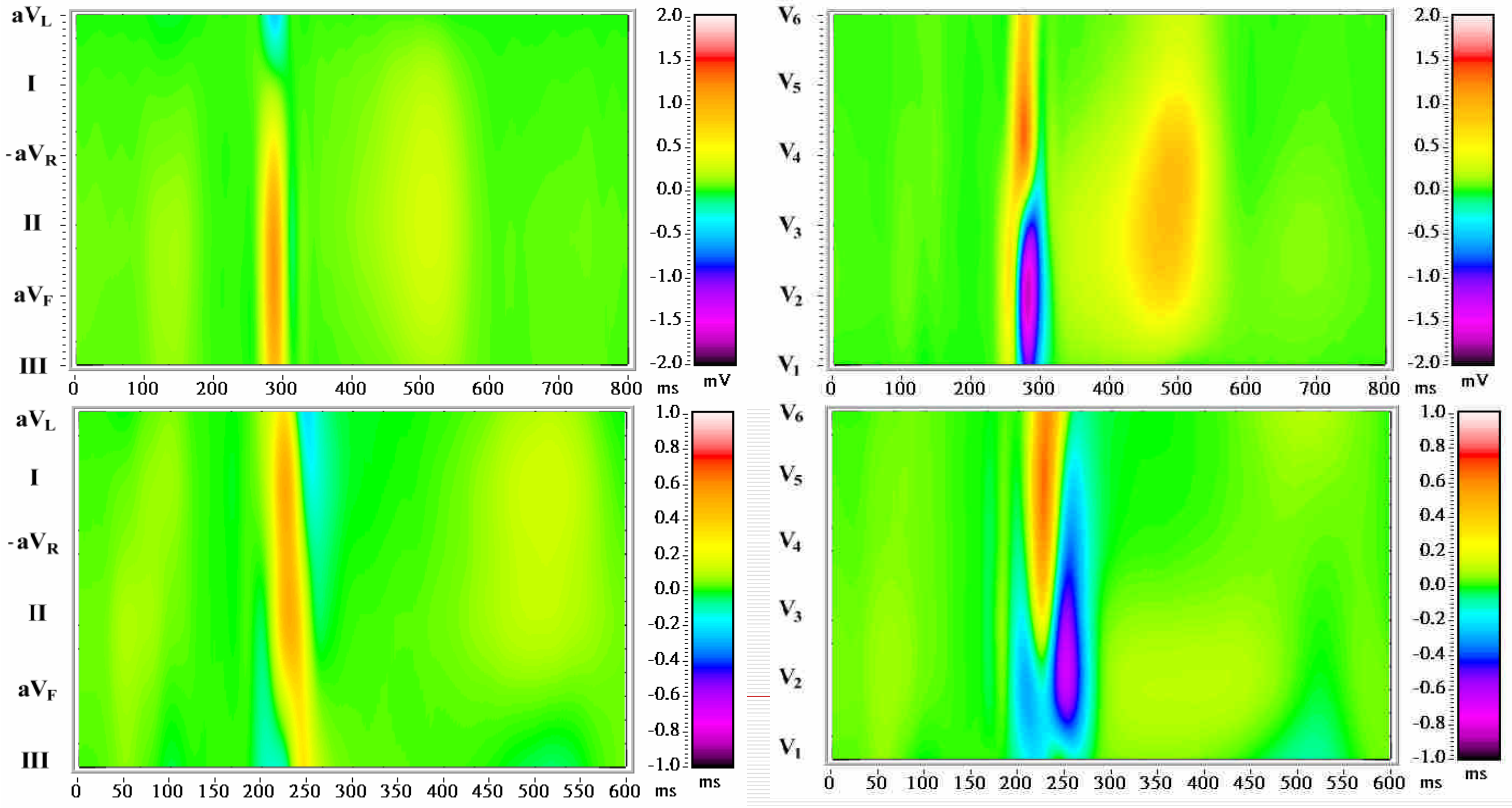
Anterior wall myocardial infarction
心室前壁梗塞



# Normal Subject 正常人 *vs.* Left Bundle-Branch Block (LBBB) 左束枝傳導阻滯



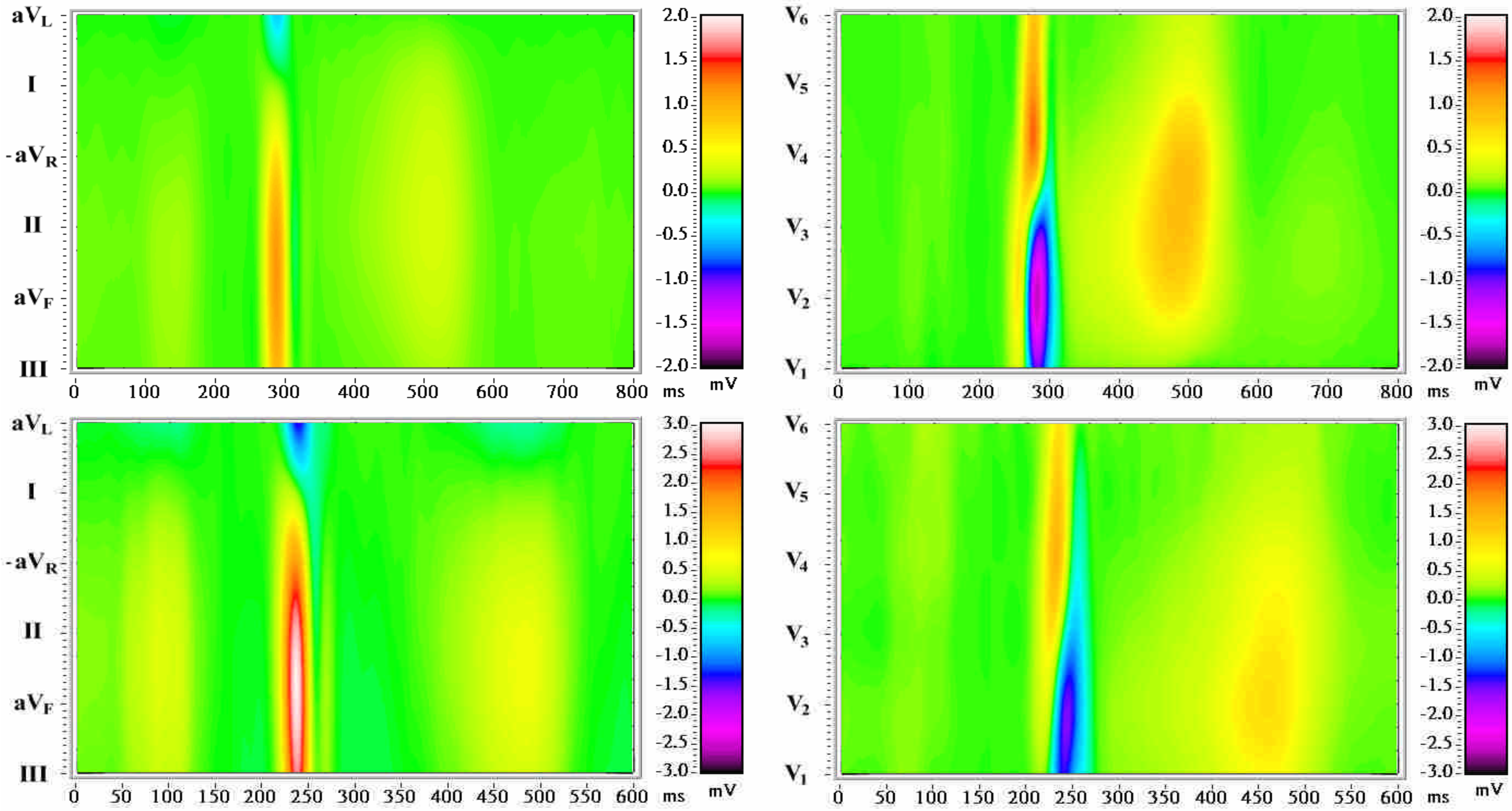
# Normal Subject 正常人 *vs.* Right Bundle-Branch Block (RBBB) 右束枝傳導阻滯



Normal Subject
正常人

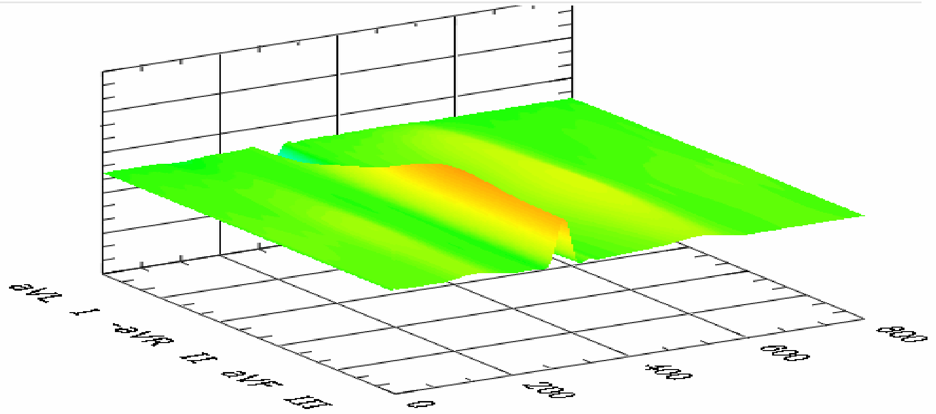
*vs.*

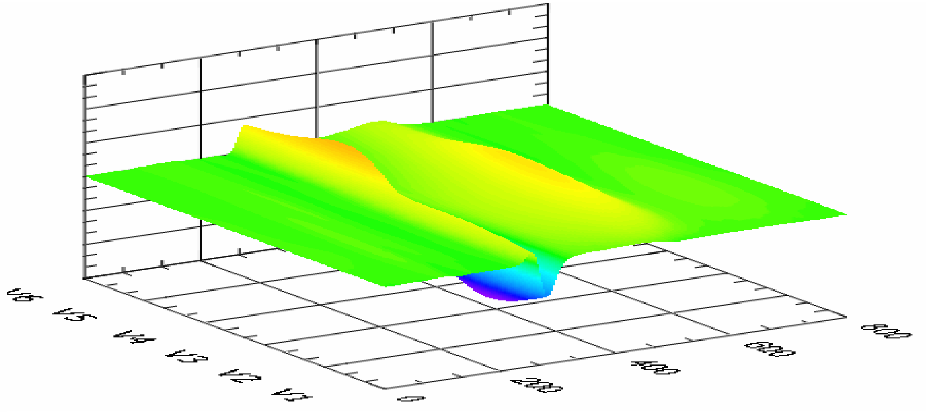
Chronic Obstructive Pulmonary Disease (COPD)
慢性阻塞性肺疾



X-axis: time scale
Y-axis: **frontal** plane
Z-axis: Amplitude

X-axis: time scale
Y-axis: **horizontal** plane
Z-axis: Amplitude

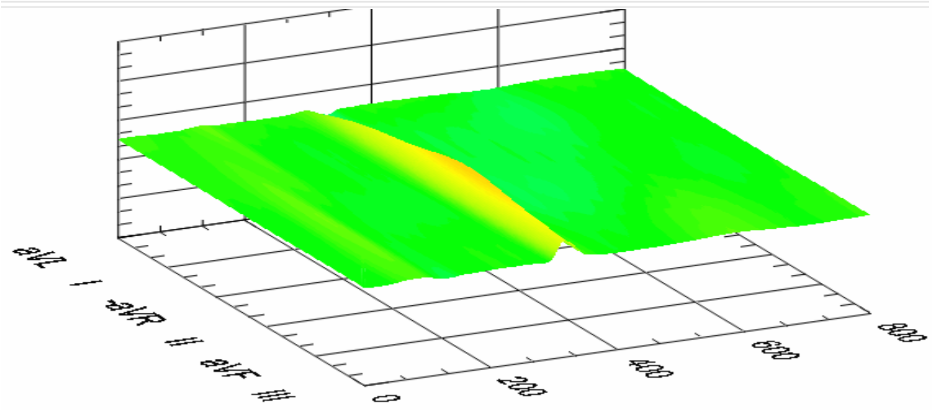


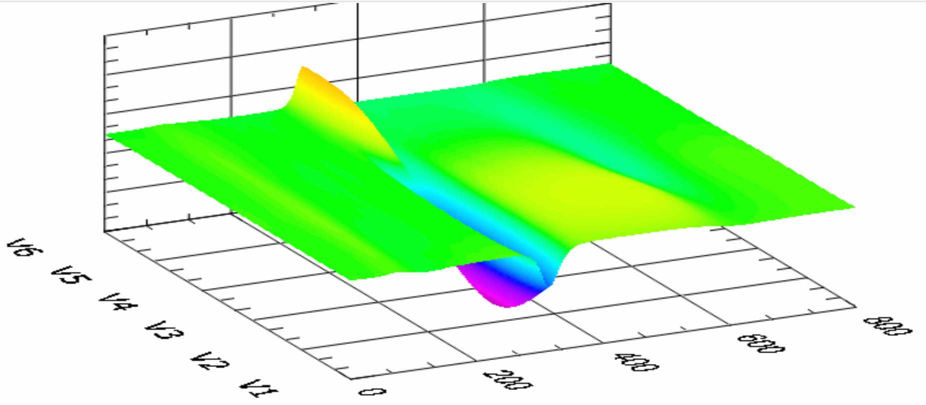




Normal Subject
正常人

*vs.*

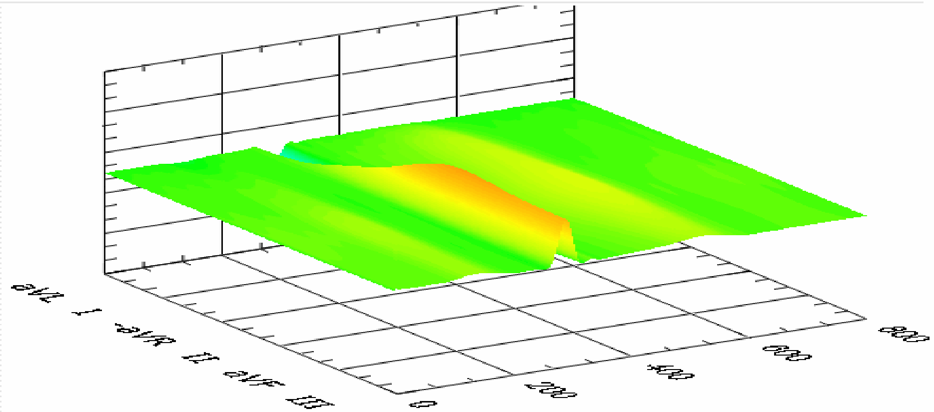
Anterior wall myocardial infarction
心室前壁梗塞

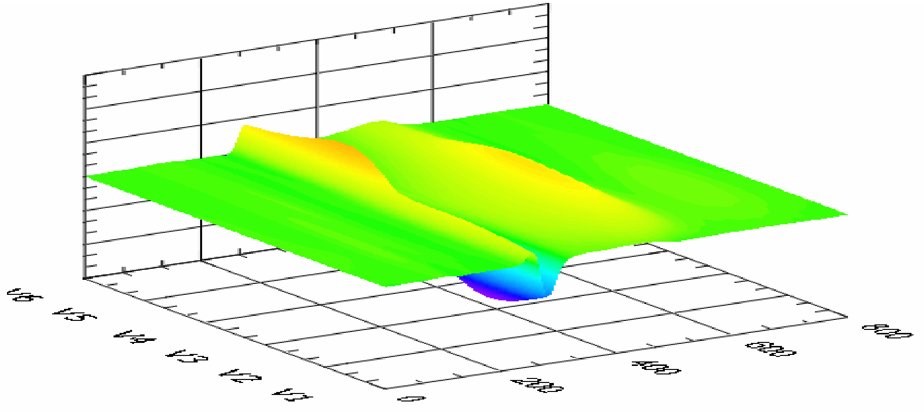


X-axis: time scale
Y-axis: **frontal** plane
Z-axis: Amplitude

X-axis: time scale
Y-axis: **horizontal** plane
Z-axis: Amplitude

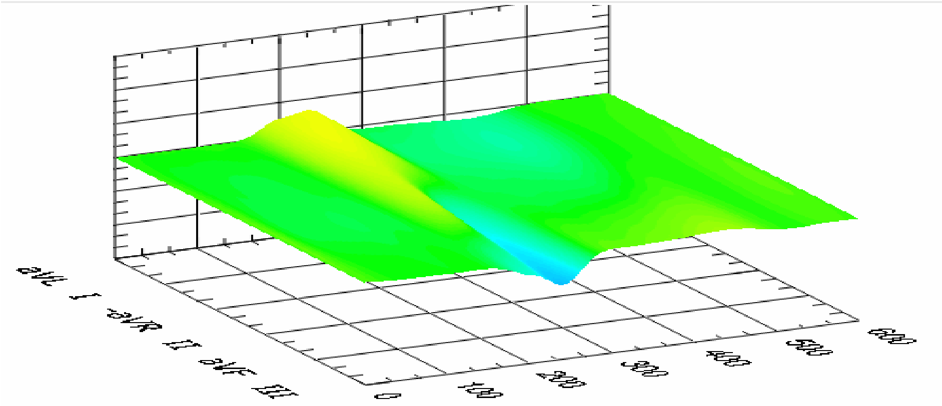


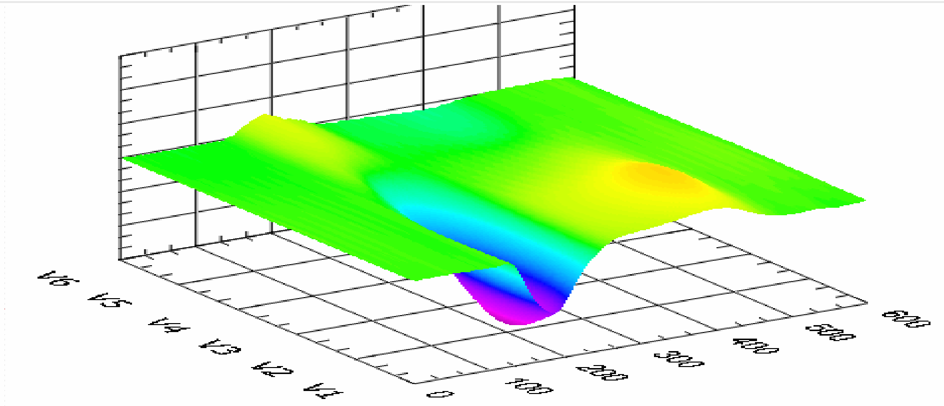




Normal Subject
正常人

*vs.*

Left Bundle-Branch Block (LBBB)
左束枝傳導阻滯



# Advantage

① Easy learning

② Compatible with 12-lead ECG

③ Integrated cardiac signal with temporal and spatial for integral view

④ Enhancement in visual perception

⑤ Powerful identification

⑥ Providing quantitative analysis results

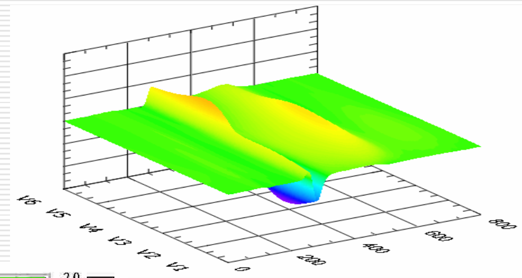
- Didn't represent the formula

# The Clinical Useful of the 3D ECG

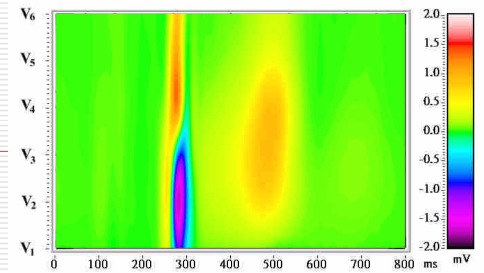
| Rating: 5 for the most favorable; 1 for the least favorable | Attending Physicians (n = 10) | Resident Physicians (n = 40) |
|---|---|---|
| 1. Is 3D ECG easier to learn than 12-lead ECG ? | $3.2 \pm 1.0$ | $2.8 \pm 0.7$ |
| 2. Is 3D ECG easier for diagnosis of cardiopulmonary diseases ? | $3.3 \pm 1.0$ | $2.9 \pm 0.7$ |
| 3. Does 3D ECG provide more information than 12-lead ECG about electric activity of the heart ? | $3.9 \pm 0.5$ | $3.1 \pm 0.9$ |
| 4. Is 3D ECG useful in diagnosis of cardiopulmo-nary diseases ? | $3.9 \pm 0.5$ | $3.1 \pm 0.9$ |
| 5. What is the clinical potential of 3D ECG ? | $3.9 \pm 0.5$ | $3.5 \pm 1.0$ |
| 6. Do you want to add 3D ECG display to your 12-lead ECG at the same price ? | $4.2 \pm 0.4$ | $3.7 \pm 0.8$ |
| 7. Can 3D ECG replace 12-lead ECG in the feature ? | $2.3 \pm 0.9$ | $3.1 \pm 0.7$ |

# Conclusion

- This new display method could not only be used as a complementary display method to the 12-lead ECG, but also provide physicians with an overall integral view about the spatial distribution of the cardiac signals.



- Visual Enhancement
  - Perspective View
  - Bird's Eye View



# Reference


[1] Batista, Leonardo Vidal, Melcher, Elmar Uwe Kurt, Carvalho, Luis Carlos, “Compression of ECG signals by optimized quantization of discrete cosine transform coefficients,” *Medical Engineering and Physics*, Vol. 23, Issue: 2, pp. 127-134, March, 2001

[2] S. G. Miaou and J. H. Larn, “Adaptive vector quantization for ECG signal compression using overlapped and linearly shifted codevectors,” *Medical & Biological Engineering & Computing*, Vol. 38, pp. 547-552, 2000. (SCI) (NSC-88-2213-E-033-029)

[3] S. Guillén*, M. T. Arredondo, V. Traver, J. M. García, and C. Fernández, “Multimedia Telehomecare System Using Standard TV Set,” *IEEE Trans. on Biomedical Eng.*, Vol. 49, No.12, Dec. 2002.

[4] 楊宗祥，三維心電圖應用於慢性阻塞性肺疾相關性研究，87 ，陽明。

[5] 張敏軒，12導程影像模式心電圖系統改進與病症資料庫建立，91 ，陽明。

[6] 薛銘彬，心肌細胞電傳導特性之研究與分析，91，東華。

[7] 詹曉龍，以數位訊號處理器為基礎的即時心率分析器設計，90，長庚。