# **Background and Related Work (20-30 page)**

**Intro to ECG(Done)**

**ECG classification history (underworking)**

**Machine learning and deep learning,**

**12 lead ECG classification,**

**Lead selected classification,**

**DISCUSS THE 12 LEAD ECG Classification benchmark technic** [**https://ieeexplore.ieee.org/document/9190034**](https://ieeexplore.ieee.org/document/9190034)

**RESNET AND X RESNET FAMILY**

* **How do we study the heart, what is ECG, and how does it start?**

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**Part1: Intro to ECG**

What is ECG (Defining ECG)?

The electrocardiogram (ECG also called EKG); it is measurement of the electrical activity of the heart using a monitor machine called electrocardiography (1), monitoring, and analyzing the changes in the heart activity, in order to diagnose cardiovascular diseases (CVDs), such as arrhythmia and myocardial infarction (6). So, it can be defined as a record or display of a patient’s heartbeat produced by electrocardiography (1). The recording shows a visual trace by placing electrodes on the skin surface of the patient’s body. An ECG electrode can be defined as a conductor through which an electrical current enters or leaves an object. The impulse originates in the SA node at a regular rate of 60–100 per minute. Each impulse is conducted down the normal pathways to the ventricles without any abnormal conduction delays; it reflects differences in trans-membrane voltages in myocardial cells that occur during depolarization and repolarization within a cycle (2).

trace expresses cardiac features that are unique to an individual (1).

An ECG can be defined as a record or display of a patient’s heartbeat produced by electrocardiography; it is the measurement of electrical activity in the heart using an ECG monitor machine, recorded as a visual trace, by placing electrodes on the patient’s skin. An ECG electrode can be defined as a conductor through which an electrical current enters or leaves an object. The impulse originates in the SA node at a regular rate of 60–100 per minute. Each impulse is conducted down the normal pathways to the ventricles without any abnormal conduction delays; it reflects differences in trans-membrane voltages in myocardial cells that occur during depolarization and repolarization within a cycle (2)

The standard 12-lead ECG has been the

gold standard for monitoring and analy -

zing changes in the heart activity, in order

to diagnose CVDs, such as arrhythmia and

myocardial infarction [1].(6)

Background

Coronary heart disease (CHD) patients require monitoring through ECGs; the 12-lead electrocardiogram (ECG) is considered to be the non-invasive gold standard. Examples of incorrect treatment because of inaccurate or poor ECG monitoring techniques have been reported in the literature.

The findings that only 50% of nurses and less than 20% of cardiologists correctly place leads V1 and V2 of a standard 12-lead ECG is of great concern. (2)

Heart diseases account for 1 million National Health Service (NHS) inpatient bed days and 5% of all emergencies medical admissions to hospital (2),

Heart failure accounts for 1 million National Health Service (NHS) inpatient bed-days and 5% of all emergency medical admissions to hospital,1 costing the United Kingdom (UK) approximately £30 billion annually.2 In 2007 coronary heart disease (CHD) led to nearly 159,000 deaths, 34% of all deaths in England.1 CHD occurs when fatty substances build up in the walls of the arteries, making the space inside narrower, and the artery becomes blocked, causing a heart attack, also known as a myocardial infarction (MI).3 CHD patients require monitoring through ECGs; the 12-lead electrocardiogram (ECG) is considered

the non-invasive gold standard for the identification of any of the conditions presented in Table 1. Nurses play a critical role in the process of obtaining, interpreting and communicating ECG findings.4 The responsibility and accountability in ECG monitoring and interpretation is extended to the nurse’s work. The nurse’s knowledge and skills in detecting any arrhythmia event

on the ECG monitors are key factors in determining the quality of nursing care.4(2)

One of the most important methods in cardiac function clinical diagnosis is using Electrocardiogram (ECG) data, represented as ECG trace. ECG has advanced computational power and medical instrumentation based on hardware and software systems that have been developed to assist ECG trace interpretation (1).

Researchers have been using ECG data as a diagnostic tool since the early 20th century; however, they have been able to apply digital analysis to the data only for the last 20 years (1). The leads were implemented and combined with signal preprocessing, wave detection, and electrocardiogram (ECG) parameter measurement (1). Then the ECG system has further developments involving separate microprocessor control modules for signal acquisition, processing, and printing plotting (1). Modules connected to personal computers were also used to design sophisticated ECG systems. Researchers have presented an economical procedure for simultaneous multichannel signal acquisition, digital real-time interference elimination and drift suppression, a real-time software QRS detector, and algorithms for wave onset and termination determination (3).

An abnormality on a preoperative ECG may lead to cancellation or delay in scheduled surgery. In clinical settings, the false diagnosis can trigger unnecessary and possibly expensive non-invasive procedures intended to characterize the extent of cardiac disease (2).

Electrocardiogram (ECG) data are traditionally acquired for clinical diagnosis of cardiac function. Dubin [1] describes the link between cardiac function and the expression of the ECGtrace. In addition, he offers a set of rules for ECG

interpretation. However, Dubin’s work uses analog methods for applying these rules.With the advances in computational power and medical instrumentation, hardware/software systems have been developed for assisted ECG trace interpretation (e.g. Siemens Medical www.smed.com> and Thought<Technologies

<www.thoughttechnology.com>). (1)

The ECGtrace contains a wealth of information. Researchers have been using ECGdata as a diagnostic tool since the early 20th century.(1)

Only in the last 20 years,however, have researchers been able to apply digital analysis to the data(1)

The most common digital application is heartrate variability (HRV) [3]. Researchers have applied numerical methods to more complex diagnostic interpretation tasks such as demixing mother–fetal signal [4], identifying(1)

atrial and ventrical fibrillation [5,6], myocardial infarction [7] and recently to characterize the uniqueness of the ECGto an individual [8–11](1)

When an abnormality appears on a preoperative ECG, it may lead to cancellation or delay in scheduled surgery. In clinical settings, the false diagnosis can trigger unnecessary and possibly expensive non-invasive procedures intended to characterize the extent of cardiac disease.11(2)

our development of microprocessor-based electrocardiographs started at the beginning of the 1980s. The first publication dealing with a complete instrument

of this type was presented by us in 1985(3)

Its implementation resulted from the decision to use a microprocessor controlled

microdot thermal printer instead of the standard at that time, which was the heated stylus type recorder with its inherent distortions and need of frequent service.(3).

The next logical step was to perform as much of the instrument functions as possible under software control.

Simultaneous acquisition of the I? standard leads was implemented and combined with signal preprocessing, wave detection, and electrocardiogram (ECG) parameter measurement.

Further developments [2] involved separate microprocessor control modules

for signal acquisition, processing, and printinglplotting. Modules connected to

personal computers were also used for design of sophisticated ECG systems.(3)

We present an economic procedure for simultaneous multichannel signal acquisition, digital real-time interference elimination and drift suppression, a real-time software QRS detector, and algorithms for wave onset and termination determination. We also discuss fast algorithms for lengthwise and crosswise lead presentation that supports the use microdot thermal printers for signal recordings(3)

Mechanics of the ECG

Measurement of the ECG signal is based on the heart’s electrical potential changes over time. When the heartbeat happens, the ECG trace shows a signal consisting of three peak complexes: P, R, and T (need figure). Heart muscle is affected by the differences happens for the chemical/potential in component cells called myocytes which have negatively charged interiors; this makes the heart physically contraction, as we call it, heartbeat. The number of heartbeats in a second is called Heartrate; the heart rate is controlled by the autonomic nervous system (ANS), ANS is composed of the sympathetic and parasympathetic systems, and they have opposite effects. Each of the two systems has independent ganglia and secretes neurotransmitters. The sympathetic system stimulates the cardiovascular system by increasing the rate of SA node firing, increasing the myocyte cell conductivity, and increasing the force of contraction; the SA node is considered the heart’s dominant pacemaker. The electrical signal radiates outward, causing the myocytes to depolarize and compress rapidly by moving sodium (NA+) ions. This is expressed as the P wave of the ECG trace; the depolarization rate slows dramatically when the signal hits the atrioventricular (AV) node, where the chemical signal changes to relatively slow-moving calcium (CA+) ions. The change in contraction is expressed as the gap between the P and the R complexes. Once past the AV node, the signal passes through to the cells lining the ventricles. The ventricles contract rapidly, which produces the R complex. Repolarization does not exactly mirror polarization due to the chemical agents and the lag between the end of the electrical impulse and physical displacement (1).

The ECG signal measures the change in electrical potential over time. The trace of each heartbeat consists of three complexes: P, R, and T. These complexes are defined by the fiducial that is the peak of each complex (Fig. 1). The labels in Fig. 1 document the commonly used medical science ECG fiducials. A heartbeat is the physical contraction of the heart muscle caused by chemical/potential differences in the component cells called myocytes. The myocytes have negatively charged interiors. The heartbeat begins with the firing of the Sinoatrial (SA) node. The SA node (Fig. 2) is the heart’s dominant pacemaker. The electrical signal radiates outward causing the myocytes to depolarize and compress rapidly by a movement of sodium (NA+) ions. This is expressed as P wave of the ECGtrace. The depolarization rate slows dramatically when the signal hits the atrio-ventricular (AV) node, where the chemical signal changes to relatively slow moving calcium (CA+) ions. The change in contraction is expressed as the gap between the P and the R complexes.

Once past the AV node, the signal passes through to the cells lining the ventricles. The ventricles contract rapidly, which produces the R complex. Repolarization does not exactly mirror polarization due to the chemical agents and the lag between the end of the electrical impulse and physical displacement [1].

The heartrate is controlled by the autonomic nervous system (ANS). ANS is composed of the sympathetic and parasympathetic system. Each of the two systems has independent ganglia and secretes neurotransmitters. The sympathetic system stimulates the cardiovascular system by increasing the rate of SA node firing, increasing the mycocyte cell conductivity, and increasing the force of contraction. The results of the sympathetic secretion of neurotransmitters are: 1. the reduction of the interbeat interval due to the increased SA firing rate, and 2. the reduction in the width of the P and T complexes due to increase conductivity.

The parasympathetic system has the opposite effect.

Diagram

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Feature ECG:

Automated ECG analysis requires wave amplitude and duration measurements (3), and it is measured with respect to an arbitrary baseline. The magnitude of the electrical potential varies with the placement of electrodes relative to the heart (1). The sensor position does not affect the observed timing of the individual P, R, and T complexes. Therefore, the temporal distances among the fiducial points are independent of the sensor placement (1); this means that the expression of the ECG trace is a function of sensor placement for electrical potential magnitude only (1).

The expression of the ECG trace is a function of sensor placement for electrical potential magnitude only. (1)

The sensor position does not affect the observed timing of the individual P, R, and T complexes. Therefore, the temporal distances among the fiducial points are independent of the sensor placement (data analysis for this is shown in Section5.1)

The ECG is measured with respect to an arbitrary baseline.

The magnitude of the electrical potential varies with the placement of electrodes relative to the heart. Diagnosticians have exploited the change in information with sensor placement to improve their understanding of cardiac performance.(1)

A picture containing text, hanger

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As part of understanding the how well the ECGbiometric can be exploited for identifying individuals, this section focuses on the relationship between changes in the ECGlead placement and identification performance. The hypothesis is that the extracted ECG attributes are invariant to placement of the ECGleads. To test this hypothesis, we collected ECGdata at two electrode placements during each session. The sensor placement locations were at the base of the neck and fifth intercostal spacing (chest). We found a strong agreement between neck and chest ECGdata (Fig. 12).(1)

Automated ECG analysis requires wave amplitude and duration measurements.(3)

ECG Leads

The concept that the leads work on in ECG systems is about the relationship between the electrical sources in the heart and the potential differences on the body’s surface (4). There are many Lead theories of how it works, i.e., Burger and vanMilaan lead theory, referred to as the volume-conductor theory (specific ref.) which included an assumption that the human body is a 3-D, bounded, irregularly shaped, and inhomogeneous volume conductor, which nevertheless still relied on a fixed-dipole hypothesis under which the potentials anywhere on the surface of the body can be derived by projecting a heart vector in 3-D space, Burger describes the theory in an equation assume the body to be a linear physical system, expresses the voltage on a given lead as a scalar product (i.e., a projection) of the heart dipole and the “lead vector “which is a vector in 3-D space that describes a certain lead. Lead vector meant a lead could be interpreted as a monitored spatial direction of cardiac electrical activity (4).

The most common ECG lead system is composed of 12-leads, the classical 12-lead electrocardiogram (ECG) requires nine electrodes to be placed strategically on the human body and one electrode to be connected to the ground [1]. The 12-lead ECG system has eight truly independent and four redundant leads (4). Other ECG lead system may use less than eight leads; the number of independent leads in a standard 12-lead ECG system. Furthermore, some systems employ more than eight leads, with some of them having more than 100 leads (2), systems that employ more than 24 leads are referred to as multichannel ECGs (MECGs) or body-surface maps (BSPMs) (2). The table shows the European and American the 12-lead ECG electrode placement and color code.

ACQUIRING a conventional 12-lead electrocardiogram (ECG) requires nine electrodes to be placed strategically on the human body and one electrode to be connected to ground [1].

the 12-lead ECG system has eight truly independent and four redundant leads(4)

it is a common characteristic of many ECG devices that they measure less than eight leads, the number of independent leads in a standard 12-lead ECG system[4]

Furthermore, there are systems that employ more than eight leads, with some of

them having more than 100 leads.[4]

ECGs produced by systems that employ more than 24 leads are referred to as multichannel ECGs (MECGs) [2] or body-surface maps (BSPMs) [3]. In between are the standard 12-lead systems extended with additional precordial and posterior leads.[4]

The review discusses the evidence base underpinning the use of 12-lead ECG electrode placement on patients with suspected heart disease and summarizes the results of 10 research papers.(2)

Table

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Lead theory describes the relationship between the electrical sources in the heart and the potential differences on the surface of the body(4)

Einthoven’s classical lead theory [10], [11] is based on the assumption that the human body is part of an infinite homogeneous conductor in which the heart’s electrical sources are represented by a single, time-varying current dipole [12]

fixed at the center of an equilateral triangle in the frontal plane, with apices corresponding to the functional positions on the limbs’ measurements sites. Note that the terms “heart dipole” and “heart vector” are used as synonyms.(4)

Burger and vanMilaan developed a more precise lead theory, referred to as the volume-conductor theory [13], [14], which included an assumption that the human body is a 3-D, bounded, irregularly shaped, and inhomogeneous volume conductor, which nevertheless still relied on a fixed-dipole hypothesis under which the potentials anywhere on the surface of the body can be derived by projecting a heart vector in 3-D space. Burger also introduced an equation that, assuming the body to be a linear physical system, expresses the voltage on a given lead as a scalar product (i.e., a projection) of the heart dipole and the “lead vector,” which is a vector in 3-D space that describes a certain lead.

There are basis leads and target leads In standard 12-lead ECG to get and record the ECG signals, 10 electrodes are used and locate on the body surface as; 4 at the limbs (left arm, right arm, left leg and right leg); The electrode placed on right leg is connected as a ground reference to prevent electrical interference from appearing on the ECG recording [2]. Six electrodes are placed across the patient's left chest (precordium) called (V1, V2, V3, V4, V5,V6), from those ten electrodes, eight independent bipolar vectors are generated, and three of these vectors are constructed from differences of electrodes at the limbs (right arm to left arm represent lead I, right arm to left leg represent lead II, and left arm to left leg represent lead III) and are linearly combined to produce the three other vectors in the frontal plane—the limb (I, II, III) and augmented leads (aVR: I to right arm, aVL: II to left arm, aVF: III to LL ). The six electrodes which placed across the patient's left chest are differenced with the average of the three limb leads (the Wilson central terminal) to give six vectors in the horizontal plane—the chest or precordial leads. These 12 vectors are highly redundant, allowing for the consideration of reducing the number of electrodes used to obtain the information in the heart vector (5).

Basis leads and target leads In standard 12-lead ECG acquisition, the ECG signals recorded from 10 electrodes are used to generate 8 independent bipolar vectors. Two of these vectors are constructed from differences of electrodes at the limbs (left and right wrists and left leg) and are linearly combined to produce 6 vectors in the frontal plane—the limb (I, II, III) and augmented leads (aVR, aVL, aVF). Six electrodes are placed across the patient's left chest (precordium) and are differenced with the average of the 3 limb leads (theWilson central terminal) to give 6 vectors in the horizontal plane—the chest or precordial leads. These 12 vectors are highly redundant, allowing for the consideration of reducing the number of electrodes used to obtain the information in the heart vector.

Each such vector represents a view of the heart's electrical activity as it is projected through the direction specified by the end points of the vector. As such, it is a sum of the global electrical activity of the heart weighted by that activity's proximity to the vector and its strength between the end points of the vector.7 Each reduced-lead system is defined by selecting an alternate set of electrode locations defined as basis leads or basis vectors, specifying how they are to be combined to create vectors defined as target leads, and specifying how they are then to be linearly combined to approximate the 12-lead via a set of linear equation coefficients.8 Each step of the selection and derivation process involves trade-offs that must be considered to fully understand the properties of the resulting reduced-lead system. (5)

ECG leads placement:

Diagram

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All the studies found that the incorrect connection of the electrode cables can alter ECG patterns simulating or concealing abnormalities, such as myocardial infarction (MI). Adherence to correct anatomical precordial lead placement methodology continues to be limited, especially with respect to leads V1 and V2

at the fourth intercostal space (ICS), which can potentially yield recorded waveforms that mimic the ECG diagnosis of septal MI.(2)

The findings that only 50% of nurses and less than 20% of cardiologists correctly place lead V1 and V2 of a standard 12-lead ECG is of great concern. (2)

Major considerations in selecting the electrode positions are acquiring the maximum amount of physiologic information content about the heart’s electrical activity, and less muscle artifacts (4). The incorrect connection of the electrode cables can alter ECG patterns simulating or concealing abnormalities, especially with respect to leads V1 and V2, the findings that only 50% of nurses and less than 20% of cardiologists correctly place lead V1 and V2 of a standard 12-lead ECG is of great concern (2).

The electrode positions are selected in such a way that they acquire the maximum

amount of “information” about the heart’s electrical activity.(4)

Several major considerations are involved in selecting basis leads: interpolation vs extrapolation, proximity to target leads, even distribution on the body surface, highest physiologic information content, and less muscle noise. Good basis leads should allow interpolation rather than extrapolation of the target leads. Interpolated leads with boundary information on both ends can be more accurately reconstructed than extrapolated leads with only 1-sided boundary information. The proximity effect also plays an important role. Choosing basis leads close to the reconstructed lead locations enables a better reconstruction than leads that are further away. Basis leads that are on the left chest and contain the most physiologic information content can contribute the best quality ECG signals for target lead reconstruction. In addition, leads that are close to chest muscles should be avoided for ambulatory applications to reduce muscle artifacts. Artifact in any recorded lead is a local effect and appears mostly in 1 lead only or 1 or 2 additional leads nearby. However, artifact in a basis lead often contaminates to a greater or lesser extent all reconstructed leads. (5)

Right arm, left arm, right leg, and left leg (Lead I,II, III, aVR, aVL, aVF). The electrode placed on right leg is connected to an acquisition system’s ground as a ground reference to prevent electrical interference from appearing on the ECG recording [2].

The 12-lead ECG is acquired using ten electrodes. Six of the ten electrodes are placed strategically on the patient’s chest (V1, V2, V3, V4, V5,V6) and the others are placed on the right(6)

Reduce ECG leads number:

Systems with reduced numbers of leads that can synthesize the 12-lead electrocardiogram (ECG) with an insignificant or a small loss of diagnostic information have been proposed.

In this paper, we review all the important systems with reduced numbers of leads together with the methodology for synthesizing the leads.

The presented theoretical and experimental justifications for the synthesis show that it is not necessary to measure a large number of leads directly, because the standard 12-lead ECG and arbitrary additional leads can be synthesized.[4]

Systems with reduced numbers of leads that can reconstruct the 12-lead electrocardiogram (ECG) with an insignificant or a small loss of diagnostic information are under study by the researchers now; they found it is not necessary to measure a large number of leads directly because the standard 12-lead ECG and arbitrary additional leads can be synthesized [4] and to overcome the disadvantage of the standard 12-lead ECG system, especially in emergencies, because an expert is needed to attach the electrodes accurately at the correct positions based on preset guidelines. Moreover, long-term monitoring of the standard 12-lead ECG is difficult owing to the wiring system involved (6). The system with the reduced number of leads is often called a “derived 12-lead ECG system” (4). The reduced lead systems are divided into two classes: systems that employ subsets of the leads from a 12-lead ECG referred to as “reduced-lead sets” and systems that use special leads. (4)

The systems with reduced numbers of leads that synthesize a 12-lead ECG are often called “derived 12-lead ECG systems” (4), These systems can be divided into two classes: systems that employ subsets of the leads from a 12-lead ECG, referred to as “reduced-lead sets” and systems that use special leads.(4)

The development of systems with reduced numbers of leads started in the 1940s, but the first important derived 12-lead ECG system came in 1968 [5] with the introduction of a derived 12-lead ECG synthesized from the orthogonal lead system previously introduced by Frank [6].(4)

Developing more comfort diagnosis systems with more efficient results by acquiring the maximum amount of information about the heart’s electrical activity and growing expectations from medical communities for standard 12-lead equivalent reconstruction were the motivations to intensify the research related to reduced-lead ECG systems in recent years (5). They are working to reduce the length of the wires and their number, and the number of electrodes. Currently, the system is a widely accepted medical technology used in several applications (5), but until now, none of these reduced-lead systems can replace the standard 12-lead system (5). By counting the advantages, Minimizing the number of electrodes which improved patient comfort, and the corresponding reduction in the number of lead wires reduces the possibility of tangled lead wires, which benefits both patient and caregiver. Also, when reduced-lead systems are used, the institutions benefit from the reduction in the cost of consumable supplies (i.e., electrodes) (5),

Reconstruction of a conventional 12-lead electrocardiogram (ECG) from a variety of reduced-lead sets has been studied for more than 2 decades (Fig. 1(5)

The development of new measuring systems is also motivated by the need for more wearing comfort, which is achieved by reducing the number of electrodes as well as the number and the length of the wires. The main aim of all new devices is to acquire the maximum amount of information about the heart’s electrical activity while using the minimum number of electrodes [7].(4)

Reduced-lead electrocardiographic systems are currently a widely accepted medical technology used in a number of applications(5)

They provide increased patient comfort and superior performance in arrhythmia and ST monitoring.(5)

In recent years,research in reduced-lead systems has intensified because of growing expectations from medical communities for standard 12-lead equivalent reconstruction(5)

Fewer electrodes increase(5) patient comfort and caregiver's convenience In routine ECG diagnosis, at the present time, none of these reduced-lead systems can replace the standard 12-lead system. The purpose of this article is to summarize

the technical challenges and considerations encountered in the lead reconstruction process and to discuss the trade-offs and limitations from an engineering point of view.(5)

Non-technical consideration of the basis and target leads In addition to the technical considerations for basis and target lead selection, patient comfort can be just as important a consideration that is often neglected. Minimizing the number of electrodes provides improved patient comfort; and the corresponding reduction in the number of lead wires reduces the possibility of tangled lead wires, which benefits both patient and caregiver. An added benefit to institutions is a reduction in the cost of consumable supplies (ie,electrodes) when reduced-lead systems are used.(5)

However, the measurement method can be impractical and cumbersome, especially in emergency situations, because an expert is needed to attach the electrodes accurately at the correct positions based on preset guidelines [3]. Moreover, long-term monitoring of the standard 12-lead ECG is difficult, owing to the wiring system involved.

To overcome the disadvantages of the standard 12-lead ECG system, several

studies have proposed systems with reduced numbers of leads that can reconstruct

the 12-lead ECG without a significant loss in diagnostic information. (6)

Each such vector represents a view of the heart's electrical activity as it is projected through the direction specified by the end points of the vector. As such, it is a sum of the global electrical activity of the heart weighted by that activity's proximity to the vector and its strength between the end points of the vector.7 Each reduced-lead system is defined by selecting an alternate set of electrode locations defined as basis leads or basis vectors, specifying how they are to be combined to create vectors defined as target leads, and specifying how they are then to be linearly combined to approximate the 12-lead via a set of linear equation coefficients.8 Each step of the selection and derivation process involves trade-offs that must be considered to fully understand the properties of the resulting reduced-lead system. (5)

ECG processing:

The ECG processing followed a logical series of experiments with quantifiable metrics. Data filters were designed based upon the observed noise sources. Fiducial points were identified on the filtered data and extracted digitally for each heartbeat. From the fiducial points, stable features were computed that characterize the uniqueness of an individual. The tests show that the extracted features are independent of the sensor location, invariant to the individual’s state of anxiety, and unique to an individual. (1)

To realize the ideal data structure (Fig. 1), the raw ECG data must be processed to remove the non-signal artifacts.

The first step is to identify the noise sources. Based upon the structure of these noise sources, a filter is designed and applied to the raw data. The filtered data is used to locate fiducials and to perform feature extraction. To best convey the processing hierarchy, all of the figures generated in this paper originate from a common data series.(1)

**power-line Interference Elimination**

Despite the high CMRR of the ECG input amplifiers, recordings are often contaminated by power-supply interference, usually phase shifted with respect to the mains voltage and containing harmonics.

ECG recordings are often contaminated with artifacts due to parasite currents through the patient’s body, differences in the electrode impedances, converting common mode interference voltages into unwanted differential signals (high CMRR), connecting cables, muscle motion, and power-supply interference, which usually seen as a phase shifted with respect to the mains voltage and containing harmonics (3). The raw ECG data must be processed to remove the artifacts to realize the ideal data structure. The first step is to design Data filters, which can be hardware and software filters, based on the observed noise sources and identify the structure of these noise sources.

This noise is due to parasite currents through the patient’s body and the connecting cables and differences in the electrode impedances, converting common mode interference voltages into unwanted differential signals [15,16]. Therefore, the

filtering of power-line interference from the ECG signals is a most important step, preceding all nther processing procedures.(3)

Most often this consists of filtering the base line and high-frequency noise. The resulting leads may be fed to the synthesis algorithm directly, or the average beat may be calculated for each lead and used in place of the source measurement.(4)

ECG with Deep learning

B. Synthesis Based on Artificial Neural Networks Even though it has been shown on numerous occasions that a linear transformation provides a high-quality synthesized ECG, it is thought that nonlinear methods like artificial neural networks (ANNs) can further improve the quality of the synthesis [8]. The obvious advantage of ANNs is their ability to synthesize signals that are not outputs from a linear system.

Therefore, the application of neural networks for the synthesis of a 12-lead ECG does not require us to assume the linearity of the heart–torso electrical system.

The basic ANN used for the purpose of the synthesis (see Fig. 5) is a feedforward ANN with an input layer composed of m neurons, each receiving samples of measured leads (9) as inputs. The output layer has 12 neurons that produce leads of the synthesized 12-lead ECG (10) on their outputs. The hidden layers make it possible to spread the data across the ANN and manage the relations between the input and output signals. The number of hidden layers is usually 1 or 2.(4)