CLUSTER INNOVATION CENTER

DIGITIZATION AND ANALYSIS OF ECG PAPER RECORDS

V.6.2 SIGNALS AND SYSTEMS ENGINEERING

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ACKNOWLEDGEMENT

We would like to express our deepest appreciation to all those who provided us with the guidance and the encouragement to carry out the project “Digitization and Analysis of ECG paper records”. We would like to acknowledge, with much appreciation, the crucial role of our mentor Prof. Shobha Bagai, who not only encouraged us, but also showed us the right direction of work and helped us with our problems at every step.

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SECTION 'A' - DIGITIZATION

SCANNING

ECG paper recordings need to be scanned. Scanning resolution can be 600/300/200 dpi (dots per inch). Preferred algorithm for the image compression is JPEG. The image can also be obtained from a digital camera used in mobile phones.

GRAY SCALING

The scanned image is then gray scaled. A grayscale digital image is an image in which the value of each pixel is a single sample, that is, it carries only intensity information. Images of this sort, also known as black-and-white, are composed exclusively of shades of gray, varying from black at the weakest intensity to white at the strongest.

IMAGE ENHANCEMENT

This step enhances the ECG image by making the signal lines sharper. Laplacian filtering is applied for making background noise lighter than the main ECG signal. This is followed by setting a threshold. Threshold value is chosen by comparing between noise pixels and pixels representing actual ECG signal. If ECG signal pixel values are close to the threshold then pixels will be made darker by subtracting a fix value. Whereas the noise pixels values, close to the threshold, will be made lighter by adding a fix value. Therefore, the resulting image will contain distinct ECG signal in the image.

We used adapthisteq() for this purpose. It enhances the contrast of the grayscale image I by transforming the values using contrast-limited adaptive histogram equalization (CLAHE).

CLAHE operates on small regions in the image, called *tiles*, rather than the entire image. Each tile's contrast is enhanced, so that the histogram of the output region approximately matches the histogram specified by the 'Distribution' parameter. The neighboring tiles are then combined using bilinear interpolation to eliminate artificially induced boundaries. The contrast, especially in homogeneous areas, can be limited to avoid amplifying any noise that might be present in the image.

MEDIAN FILTRATION

The median filter is a nonlinear digital filtering technique, often used to remove noise. Such noise reduction is a typical pre-processing step to improve the results of later processing (for example, edge detection on an image). Median filtering is very widely used in digital image processing because, under certain conditions, it preserves edges while removing noise

Actual ECG signal recorded by an ECG machine can be degraded due to presence of noise. Various sources of noise can be:

i. Item Power Line Interface (50Hz or 60Hz noise from power lines)
ii. Baseline wander (low frequency noise)
iii. Muscle noise
iv. Other interference (i.e., radio frequency noise from other equipment)

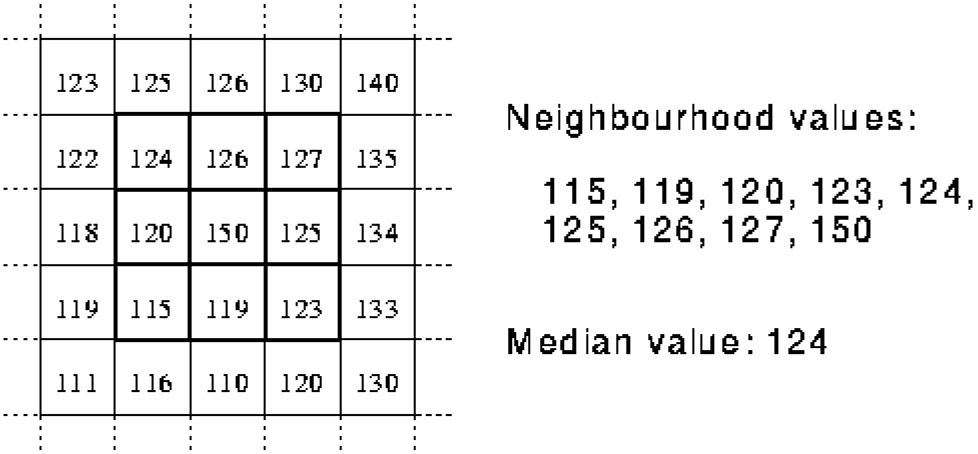
Noisy signal can result into misdiagnosis so it is desirable to remove noise from the actual ECG signal as much as possible. A noisy ECG signal image is taken and the performance of various filters including median filter.

Median filters are nonlinear:

Median[A(x)+B(x)] $\neq$ Median[A(x)] + Median[B(x)] This must be taken into account if we plan on summing filtered images.

How is it done?

- In median filtering, the neighboring pixels are ranked according to brightness (intensity) and the median value becomes the new value for the central pixel.
- Median filters can do an excellent job of rejecting certain types of noise, in particular, “shot” or impulse noise in which some individual pixels have extreme values.
- In the median filtering operation, the pixel values in the neighborhood window are ranked according to intensity, and the middle value (the median) becomes the output value for the pixel under evaluation.



123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

Neighbourhood values:

115, 119, 120, 123, 124,
125, 126, 127, 150

Median value: 124

Advantages:

• The median is, in a sense, a more robust “average” than the mean, as it is not affected by outliers (extreme values).
• Since the output pixel value is one of the neighboring values, new “unrealistic” values are not created near edges.

INTERPOLATION

Now that we have plotted the ECG signal and is ready to be analyzed the final step required is of determining the function using the points on the plot. This function is necessary for us in further analysis and comparison with other ECG signal.

Interpolation is the best way to that.
Newton’s method is what we have used here, given below is a brief description of it.

- Newton’s interpolation formula is mathematically equivalent to the Lagrange’s formula, but is much more efficient.
  - One of the most important features of Newton’s formula is that one can gradually increase the support data without recomputing what is already computed.
- Divided Difference:
  - Let $P_{i0i1\ldots ik}$ (t) represent the k-th degree polynomial that satisfies $P_{i0i1\ldots ik}(x_{ij}) = f_{ij}$ (1)
    for all j = 0, . . . , k.

  - The recursion formula holds:

    $P_{i0i1\ldots ik}(t) = \frac{(t - x_{i0})P_{i1\ldots ik}(t) - (t - x_{ik})P_{i0\ldots ik-1}(t)x_0}{x_{ik} - x_{i0}}$

    (2) .

    - The right-hand side of (??), denoted by R(t), is a polynomial of degree ≤ k.
    - $R(x_{ij}) = f_{ij}$ for all j = 0, . . . , k.
    - That is, R(t) interpolates the same set of data as does the polynomial $P_{i0i1\ldots ik}(t)$. .
    - By uniqueness, $R(t) = P_{i0i1\ldots ik}(t)$.
  - The difference $P_{i0i1\ldots ik}(t) - P_{i0i1\ldots ik-1}(t)$ is a k-th degree polynomial that vanishes at x_{ij} for j = 0, . . . , k − 1. Thus we may write $P_{i0i1\ldots ik}(t) = P_{i0i1\ldots ik-1}(t) + f_{i0\ldots ik}(t - x_{i0})(t - x_{i1}) \ldots (t - x_{ik}-1)$. (3)
  - The leading coefficients fi0...ik can be determined recursively from the formula (??),

    i.e.,

    $$f_{i0\ldots ik} = \frac{f_{i1\ldots ik} - f_{i0\ldots ik-1} - 1xik}{x_{ik} - x_{i0}} \quad (4)$$

    where $f_{i1\ldots ik}$ and $f_{i0\ldots ik-1}$ are the leading coefficients of the polynomials $P_{i1\ldots ik}(x)$ and $P_{i0\ldots ik-1}(x)$, respectively.

- Let $x_0, \ldots, x_k$ be support arguments (but not necessarily in any order) over the interval [a, b]. We define the Newton's divided difference as follows:

  $$f[x_0] := f(x_0) \quad (5)$$

  $$f[x_0, x_1] := \frac{f[x_1] - f[x_0]}{x_1 - x_0} \quad (6)$$

  $$f[x_0, \ldots, x_k] := \frac{f[x_1, \ldots, x_k] - f[x_0, \ldots, x_{k-1}]}{x_k - x_0} \quad (7)$$

- The k-th degree polynomial that interpolates the set of support data $\{(x_i, f_i) | i = 0, \ldots, k\}$ is given by $P_{x0\ldots xk}(x) = f[x_0] + f[x_0, x_1](x - x_0) + \ldots + f[x_0, \ldots, x_k](x - x_0)(x - x_1) \ldots (x - x_{k-1})$.

SECTION 'B' - ANALYSIS AND COMPARISON OF ECG SIGNALS

The main motive of this section is to study the ECG and do the comparison of a perfect ECG to the one of a heart patient (a normal and an abnormal ECG). In this section we'll be covering the application of impulse signal in an artificial pace maker.

PACEMAKER

A pacemaker is a small device that's placed in the chest or abdomen to help control abnormal heart rhythms. This device uses electrical pulses to prompt the heart to beat at a normal rate.

Pacemakers are used to treat arrhythmias (ah-RITH-me-ahs). Arrhythmias are problems with the rate or rhythm of the heartbeat. During an arrhythmia, the heart can beat too fast, too slow, or with an irregular rhythm.

A heartbeat that's too fast is called tachycardia (TAK-ih-KAR-de-ah). A heartbeat that's too slow is called bradycardia (bray-de-KAR-de-ah).

During an arrhythmia, the heart may not be able to pump enough blood to the body. This can cause symptoms such as fatigue (tiredness), shortness of breath, or fainting. Severe arrhythmias can damage the body's vital organs and may even cause loss of consciousness or death.

A pacemaker can relieve some arrhythmia symptoms, such as fatigue and fainting. A pacemaker also can help a person who has abnormal heart rhythms resume a more active lifestyle.

METHODOLOGY:

We have the ECG paper records of a healthy person and a heart patient (a normal and an abnormal ECG sample). We digitized it as shown in the first section and then calculated the impulse an artificial pacemaker needs to provide to the patient in order to make the heart work perfectly.

We can now segregate the two signals as the normal signal and the abnormal signal, using the convolution theorem we can the impulse signal.

CONVOLUTION THEOREM

Let $f(t)$ and $g(t)$ be arbitrary functions of time t with Fourier transforms. Take

$$f(t) = \mathcal{F}_\nu^{-1}[F(\nu)](t) = \int_{-\infty}^{\infty} F(\nu)\, e^{2\pi i \nu t}\, d\nu \tag{1}$$

$$g(t) = \mathcal{F}_\nu^{-1}[G(\nu)](t) = \int_{-\infty}^{\infty} G(\nu)\, e^{2\pi i \nu t}\, d\nu, \tag{2}$$

where $\mathcal{F}_\nu^{-1}(t)$ denotes the inverse Fourier transform (where the transform pair is defined to have constants $A = 1$ and $B = -2\pi$). Then the convolution is

$$f * g \equiv \int_{-\infty}^{\infty} g(t')\, f(t - t')\, dt' \tag{3}$$

$$= \int_{-\infty}^{\infty} g(t') \left[\int_{-\infty}^{\infty} F(\nu)\, e^{2\pi i \nu (t - t')}\, d\nu \right] dt'. \tag{4}$$

Interchange the order of integration,

$$f * g = \int_{-\infty}^{\infty} F(\nu) \left[\int_{-\infty}^{\infty} g(t')\, e^{-2\pi i \nu t'}\, dt' \right] e^{2\pi i \nu t}\, d\nu \tag{5}$$

$$= \int_{-\infty}^{\infty} F(\nu)\, G(\nu)\, e^{2\pi i \nu t}\, d\nu \tag{6}$$

$$= \mathcal{F}_\nu^{-1}[F(\nu)\, G(\nu)](t). \tag{7}$$

So, applying a Fourier transform to each side, we have

$$\mathcal{F}[f * g] = \mathcal{F}[f]\, \mathcal{F}[g]. \tag{8}$$

The convolution theorem also takes the alternate forms

$$\mathcal{F}[f\, g] = \mathcal{F}[f] * \mathcal{F}[g] \tag{9}$$

$$\mathcal{F}^{-1}(\mathcal{F}[f]\, \mathcal{F}[g]) = f * g \tag{10}$$

$$\mathcal{F}^{-1}(\mathcal{F}[f] * \mathcal{F}[g]) = f\, g. \tag{11}$$

We take Fourier transform of both the normal and the abnormal signals, dividing Fourier transform of the normal signal by the Fourier transform of the abnormal signal, we'll get the Fourier transform of the impulse response.

On applying the inverse Fourier transform on the output we'll get the impulse response. Now this impulse response is what is to be provided by the pacemaker to stabilize functioning of heart in an unhealthy person.

RESULTS

ORIGINAL INITIAL IMAGE

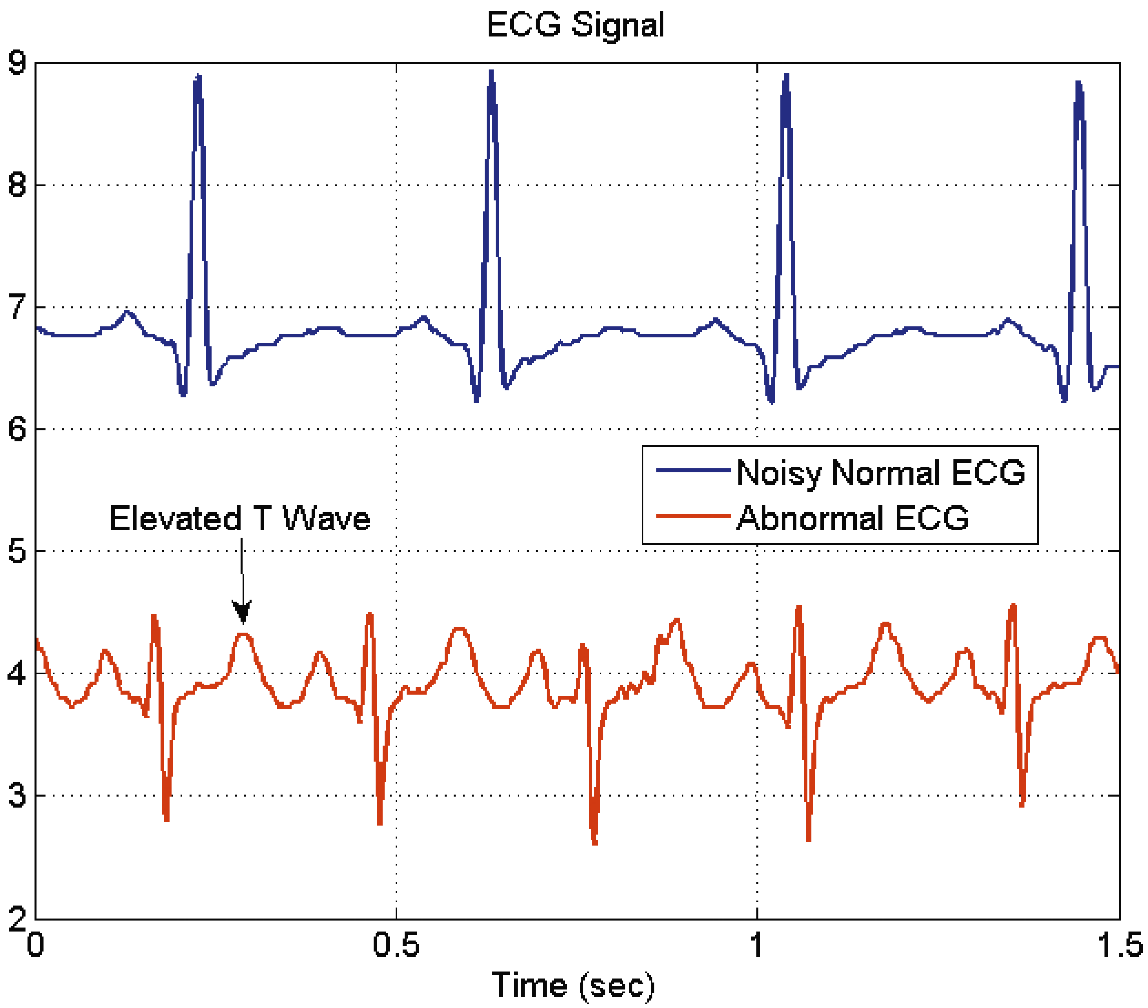


FIGURE 1: Original Initial Image

(src: https://lh4.googleusercontent.com/-nea0zgbataw/tw5owvdyeii/aaaaaaaaadc/qd44y9crrte/s1600/uwash_fig3_wl.gif)

CROPPED IMAGES

Approximated single cycles of both the normal and the abnormal waves are cropped to be given as input for enhancement.

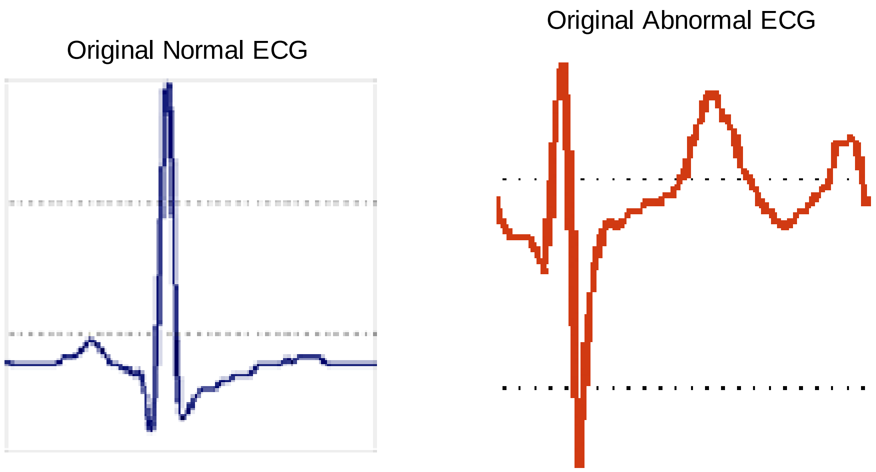


FIGURE 2: Input Image cropped from FIGURE 1

ENHANCED IMAGES

The images in FIGURE 2 are then enhanced using the image enhancement as stated in section A.

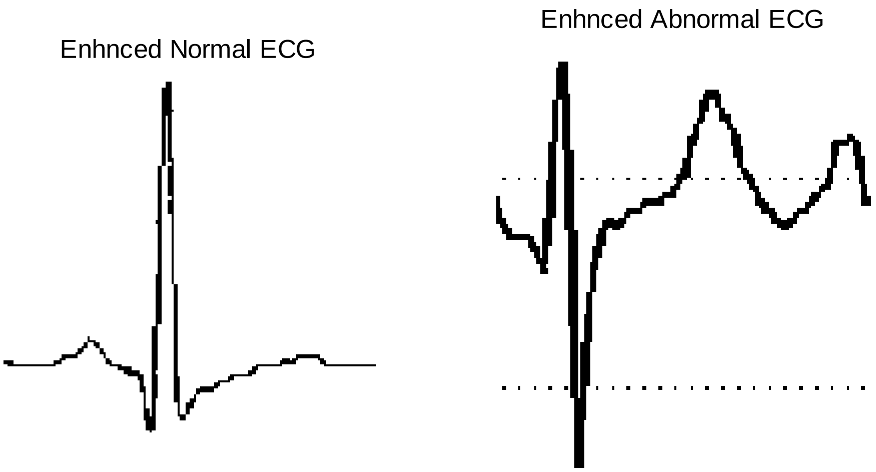


FIGURE 3: Enhanced Image

PLOTTING DATA POINTS

After enhancement, the left bottom is taken as the origin position, (0, 0), and the points are plotted as shown below.

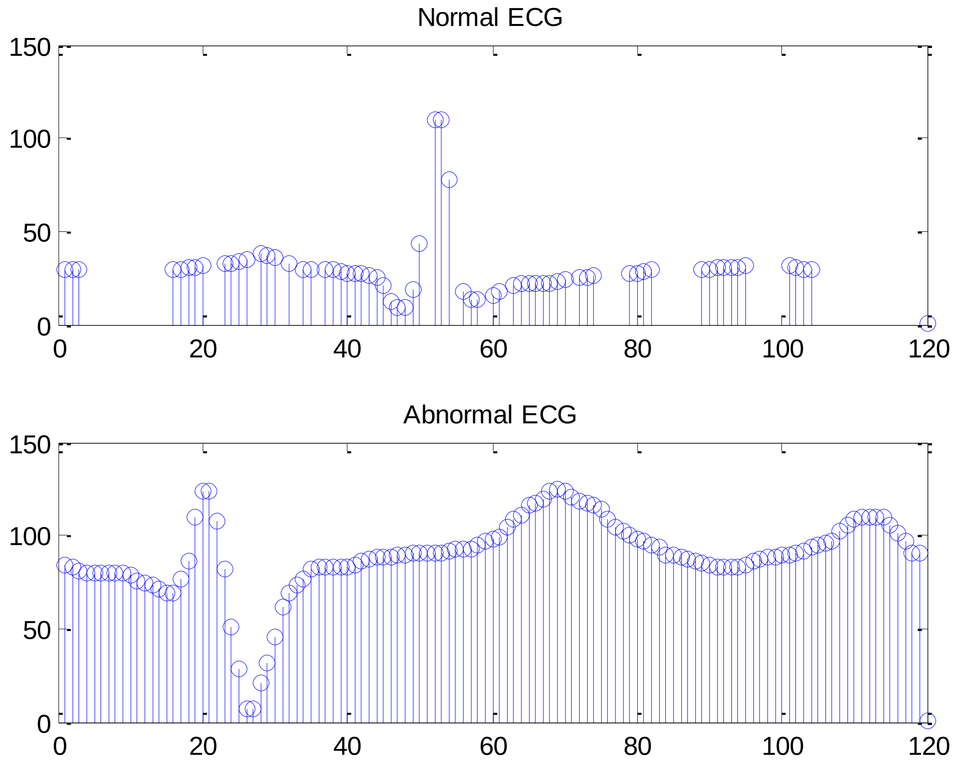


FIGURE 4: Data Points With Left Bottom As Origin (0,0)

PLOTS WITH CORRECTED BASELINE

To determine +ve and -ve deflections from the ECG wave, a baseline is to be selected. In biomedical terminology, the baseline is chosen as that point which occurred the maximum number of times in the signal. So, the mode of the plot becomes the origin point.

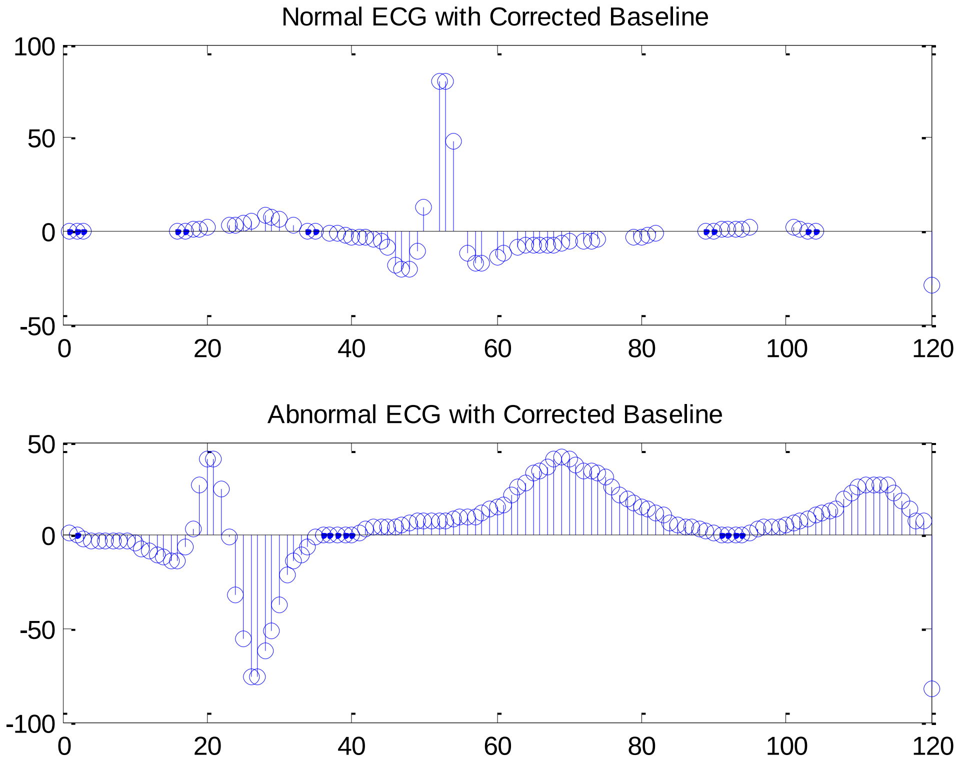


FIGURE 5: CORRECTED BASELINE

PLOT OF FOURIER TRANSFORM OF IMPULSE RESPONSE AND IMPULSE RESPONSE

$$Normal\ ECG = Abnormal\ ECG * Impulse\ Response$$

$$\updownarrow\ FT \qquad \updownarrow\ FT \qquad\qquad \updownarrow\ FT$$

$$FT(Normal\ ECG) = FT(Abnormal\ ECG)\ \times FT(Impulse\ Response)$$

$$FT(Impulse\ Response) = FT(Normal\ ECG)/FT(Abnormal\ ECG)$$

$$FT^{-1}\big(FT(Impulse\ Response)\big) = Impulse\ response$$

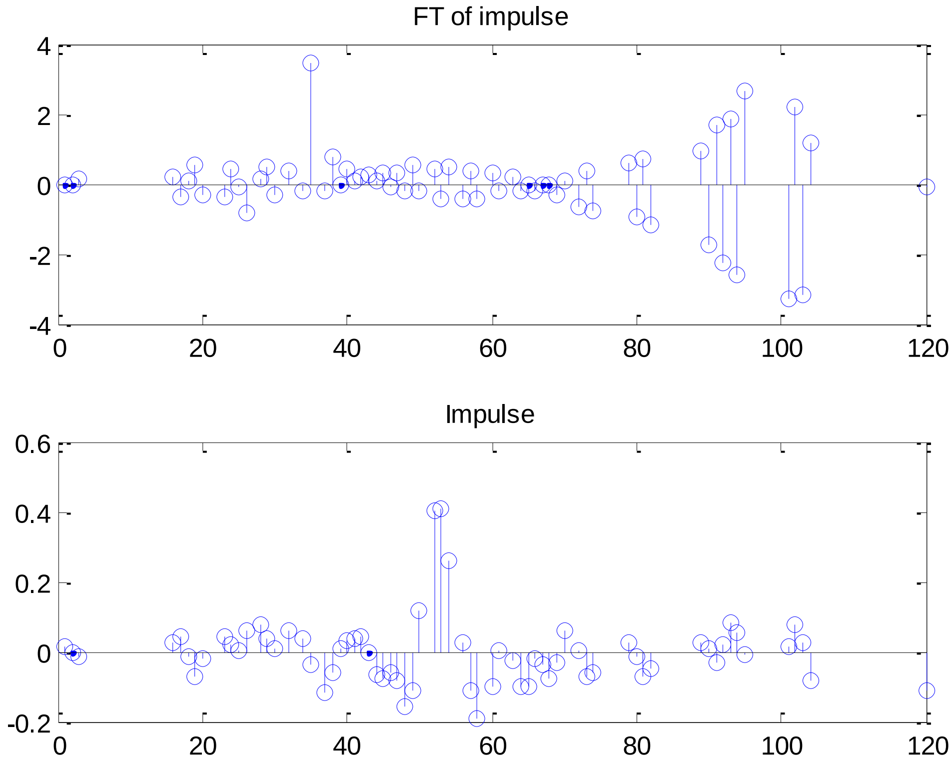


FIGURE 6: Fourier Transform of impulse response and impulse response

CONCLUSIONS

The section A of this report, Digitization of the ECG Waveform, can be used to convert the ECG waveform that we obtain from the ECG Scanner on thermal papers, to a digital form. Once we have the wave in digital form, we can apply operations such as sampling, scaling, modulation etc. for the analysis of the wave.

The impulse response calculated and plotted in FIGURE 6 in section B can be generated using the pacemaker to remove the abnormalities of the heart and achieve a regular ECG waveform.

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