Sudden Cardiac Arrest Detection

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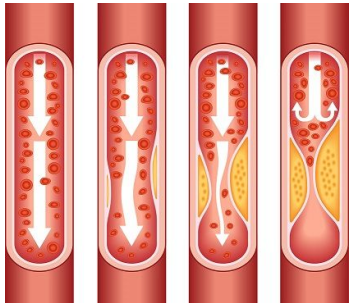
Problem Statement

Sudden Cardiac Arrest (SCA):

- Sudden Cardiac Arrest (SCA) accounts for approximately 325,000 deaths per year [1]
  - Greater than the total death rate of breast cancer, lung cancer, and HIV/AIDS combined
- Survival rate of only 33% if the arrest is witnessed by another individual, and only 10.6% if the person is alone [1]

Possible Cardiac Arrest Cause:

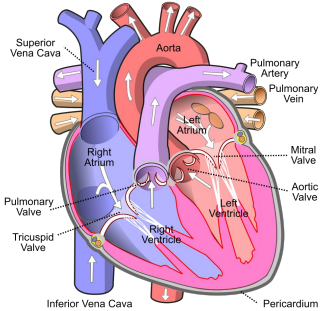
Plaque buildup in arteries causes restricted blood flow, leading to complications



Center for Disease Control
https://www.cdc.gov/heartdisease/facts.htm

Motivation

- Gives us the opportunity to learn about the heart and how it generates its beat
- Learn about how other smart ECG technology works
- Help others using our electrical and biomedical engineering knowledge
- Represents MSU well and is a chance to be creative



Wikipedia
https://en.wikipedia.org/wiki/Heart#/media

Michigan Radio
http://www.michiganradio.org/post/michigan-state-name

Apple Inc.
https://www.apple.com/apple-watch-series-4/health

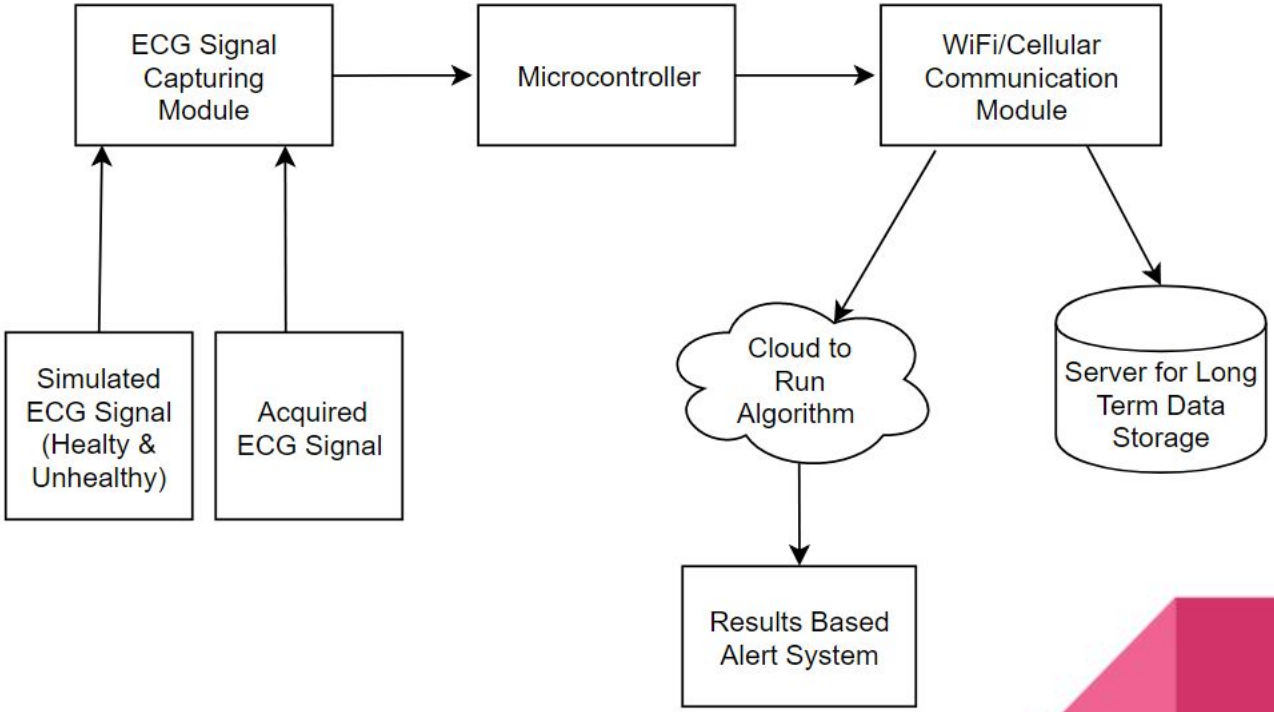
Background

- We would like to develop a system that detects cardiac arrest in real time
- Utilizes cloud, statistics, algorithms, hardware devices, memory management, Apple Watch 4 (FDA Approved)

Process:

1. Cloud receives data from ECG Enabled Smart Watch
2. Data is grouped in chunks and sent to cloud
3. Algorithm captures data from server via cloud
4. Algorithm raises flag if signs of SCA are detected
5. Alert sent to user via UI and GSM

High Level Design



Current Technology

Apple Watch Series 4

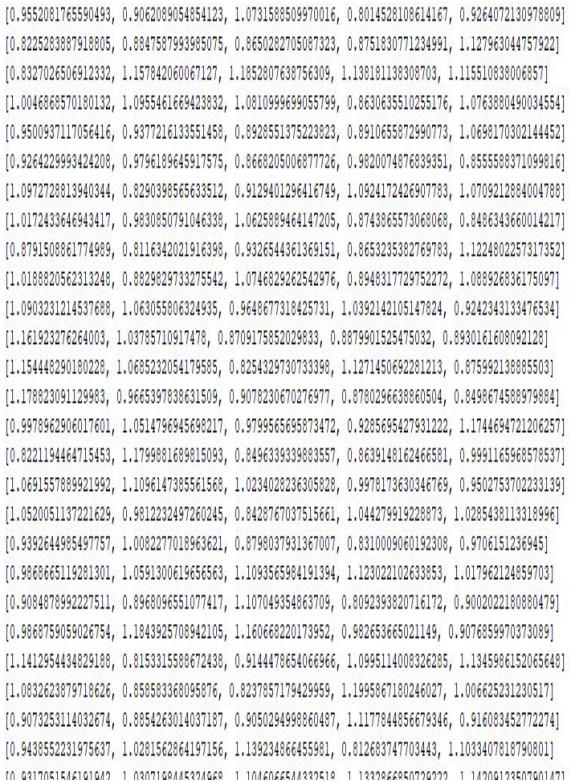
- FDA approved as of September 12th, 2018 [6]
- Has reliable ECG signal capturing method
- Well established ecosystem, with 24 million smart watches sold [6]
- No sudden cardiac arrest detection technology

Apple Inc.
https://www.apple.com/apple-watch-series-4/health/

iBeat

- Not currently FDA approved [7]
- Relatively new company making grandiose claims
- Similar technology as this project aims to achieve
    - Not specifically for sudden cardiac arrest detection

Algorithm Block Part 1




```python
# rrmean algorithm cal
def rrmean(line):

    # remove end brackets (strings are immutable)
    line = line.replace('[','')
    line = line.replace(']', '')

    # create list of strings separated by comma
    valListCopy = line.split(',')

    # Convert string elements to double
    valList = [float(i) for i in valListCopy]

    # param N is how many entries/data points
    n = len(valList)

    # start sum at init 0
    totalSum = 0

    # sum up the data point values in the list of floats
    for i in range(n):
        totalSum += valList[i]
        i = i+1

    # get the sum needed for the average variable below
    totalSum = sum(valList)

    # total sum divided by the length of the list of numbers
    avg = totalSum/n

    # return the average
    return (avg)
```

Priorities:

Efficiency (Real Time Detection)

- Data must be setup as “chunks” to implement cache memory management methodologies.

Mean (Average)

- Data is parsed line by line then run through the RR-mean function.

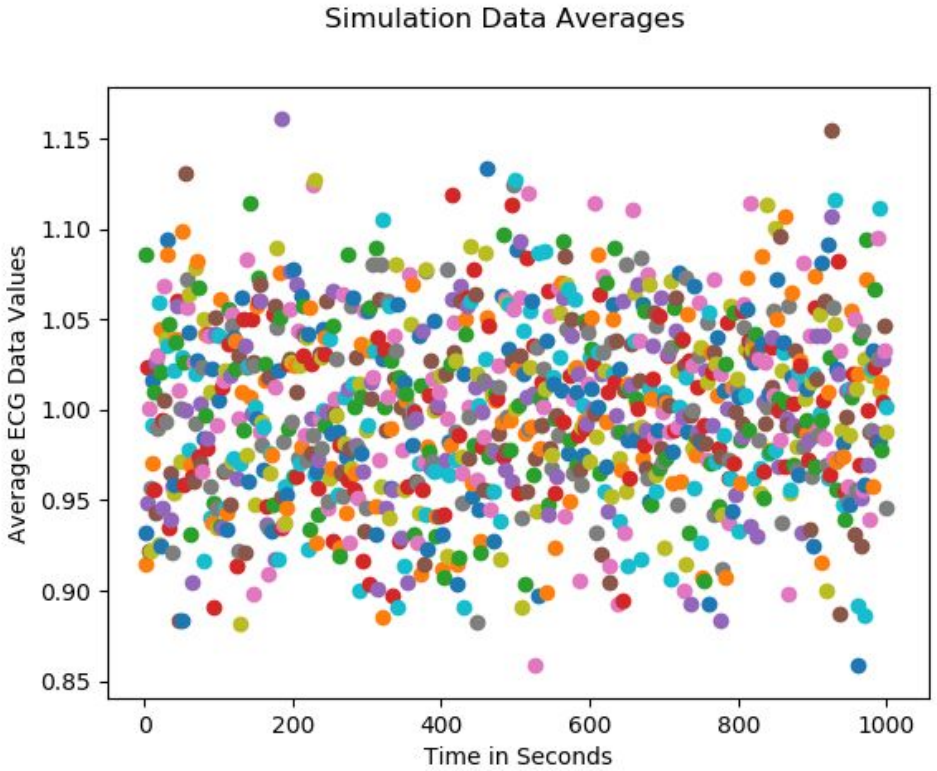
Plots

- Data must be displayed to data scientists in ways they can understand and use.

$$RR_{mean} = \frac{1}{N}\sum RR(i)$$

Content in images created by Mark Maroki
github.com/Algorithmism

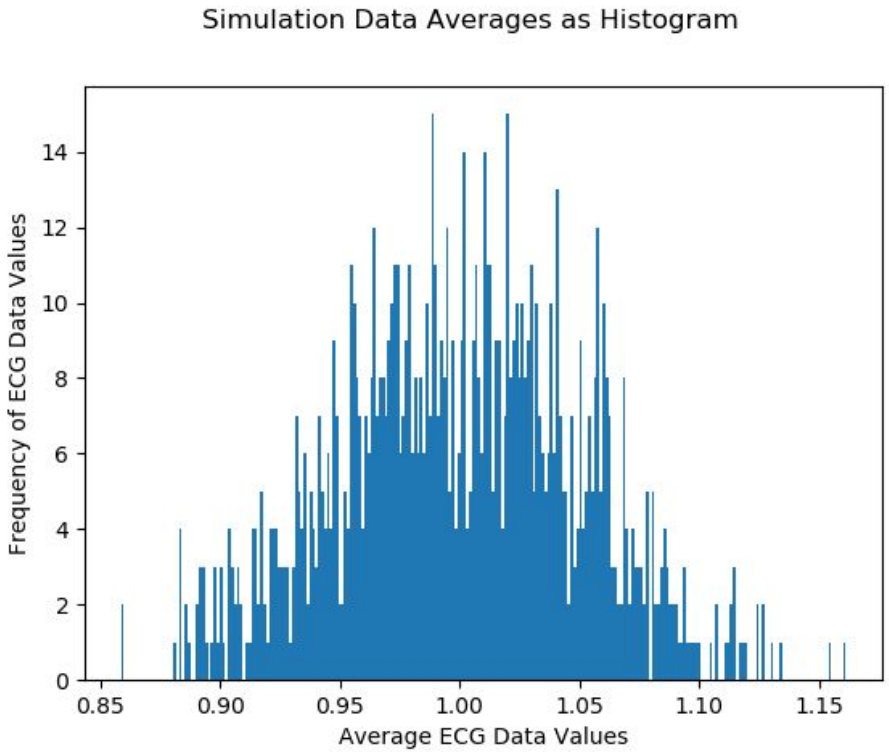
Scatter Plot of Simulated Data Averages



The scatter plot (left) displays the results average of simulated ECG test data over 1000 seconds.

- This test data can be used to get the average heart beat range of a user.
- Tells general range and exact averages of data.

Mean of Simulated Data

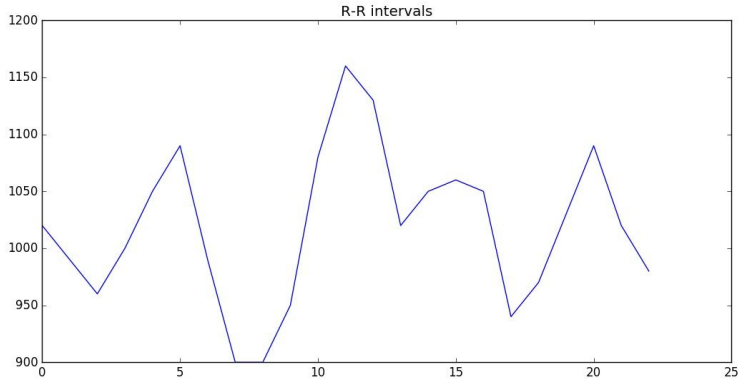


- Helps better understand the average heart rate of one specific patient.
- Organizes the scatter plot data as a histogram to help observers draw conclusions from the data.
- Ex: One can use this data to personalize normal vs abnormal heart rates by calculating the standard deviation from mean

Algorithm Blocks

$$RMSSD = \sqrt{\frac{1}{N}\sum (RR(i+1) - RR(i))^2}$$

- Calculates the RR intervals and Root of the Mean Squared for heart rate
- The data does not have sharp spikes of volatility as shown on the right
- SCA patients typically have higher RMSSD levels

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    line = line.replace(']', '')

    # create list of strings separated by comma
    valListCopy = line.split(',')

    # Convert string elements to double
    valList = [float(i) for i in valListCopy]

    # param N is how many entries/data points
    n = len(valList)

    # start sum at init 0
    totalSum = 0

    # sum up the data point values in the list of fl
    for i in range(1, n):
        totalSum += valList[i]
        i = i+1

    # get the sum needed for the average variable be
    totalSum = sum(valList)
    totalz = valList.pop();

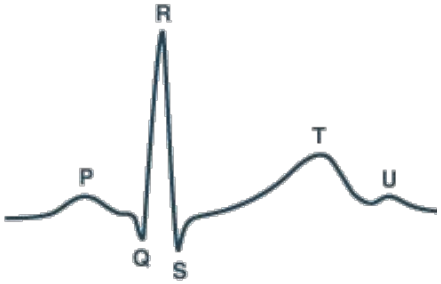

# total sum divided by the length of the list of num
avgSSD = totalSum/n
avg = totalz/n
finalform = (avgSSD-avg)**2

    # return rmssd
    return finalform

#close main
main()
```

- Rmssd formula implemented in Python
- Plot data in main.

Algorithm Data Analysis



ECG Waveform
https://www.analog.com/en/analog-dialogue/articles/ecg-front-end-design-simplified.html

Mean R-R Interval Duration:

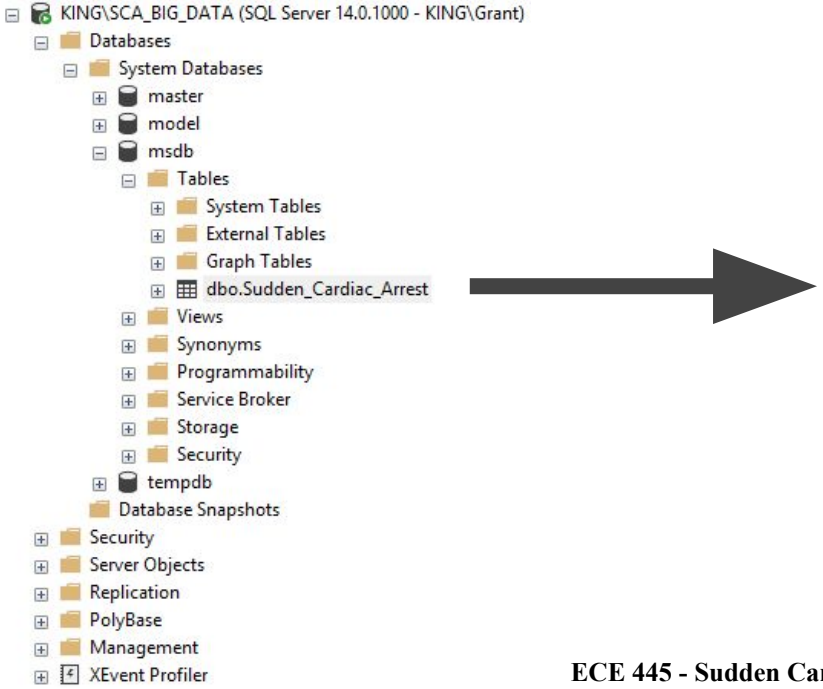
- 90% of sudden cardiac arrest patients experienced an R-R to interval duration between 690-1100 ms [3,4]
  - Data will be processed to flag patients outside of set limits
- From R-R duration data points, heart rate can be computed for selected time durations

Square Root of the Mean Differences of all Adjacent R-R intervals:

- Downward slope experienced 3 hours prior to sudden cardiac arrest onset [1]
- Major spike experienced 3 minutes prior to sudden cardiac arrest onset [1]
- Will aid in the characterization of heart rate variability

SQL Server

Connection Path:



Data to be Stored

Column Name	Data Type	Allow Nulls
[Date of Entry]	datetime	☐
[User ID]	nchar(100)	☐
[User Age]	int	☐
[User Address]	nchar(150)	☐
[R-R Interval (Previous Two Entries)]	float	☐
[Root of the Mean Differences of all Adjacent R-R]	float	☐
[Average Heart Rate]	float	☐
[Peak Q Wave Amplitude]	float	☐
[Peak R Wave Amplitude]	float	☐
[Peak S Wave Amplitude]	float	☐
[Q-Q Interval (Previous Two Entries)]	float	☐
[S-S Interval (Previous Two Entries)]	float	☐
[Risk Status]	binary(1)	☐

Server

Purpose:

- Provides long term data storage for user's heart information
- Allows for the characterization of a user's heart health over long periods of time
- Remove the burden of data storage from the cloud

Advantages:

- Easily modifiable to allow for new data to be added to the system
- Data is accessible through convenient means
- SQL is quickly integrated into various ecosystem
- Capable of supporting big data

Hewlett Packard Enterprises
http://www.eliasworldmedia.com/HewlettPackardEnterprise/

Jenkins Job

- Jenkins Pipeline created to provide triggers to automate system.
- Data is entered into the pipeline thus triggering the pipeline.
- Data is entered into the python script algorithm to detect SCA.
- This process also monitors the health of the system.

Hardware - ECG Signal Capturing Device

- QUASAR IBEv2 ECG Sensors can be used to capture user heart rate in real-time
  - Detects biopotentials at the uV level [8]
  - Incorporates biopotential amplifier [8]
    - *Typical Heart Biopotential Amplitude: 1-5 mV* [9]
  - Uses low dielectric material to sense at low capacitive levels [8]
    - Is not affected by rigourous motion and day-to-day movement
  - Compact and wearable
  - No skin contact is required

Wearable Sensing
https://wearablesensing.com/files

Hardware - Microcontroller

- The Atmel ATMEGA1281V microcontroller (or similar microcontroller) can be used to process incoming heart rate
  - Incoming heart rate will be converted using integrated 10-bit ADC [10]
  - Heart rate will be sampled and temporarily stored
  - Can temporarily store up to 8 kB of data [10]
  - Memory size of 128 kB [10]

Wearable Sensing
https://www.mouser.com/ProductDetail/Microchip-Technology-Atmel/ATMEGA1281V

Hardware - WiFi/Cellular Communication Module

- Rainsun 2.4 GHz Wireless chip antenna with BlueTooth capabilities
- The nRF24E1 2.4 GHz Radio Transceiver with Microcontroller from Nordic Semiconductor
  - Transceiver continuously transmits and receives digitized ECG signal
    - Data transmission rate up to 250 kbps [11]
  - Additional microcontroller further fine tunes data sampling of digitized signal [8]
  - Additional integrated ADC can increase signal's resolution [8]

Rainsun
http://www.rainsun.com/wp-content/uploads/

Alert System

- If an irregular heartbeat pattern is detected by the algorithm:
  - Communication Module will receive the alert signal
  - A digital alert will be displayed on user's watch
  - Alerts will be sent from cloud to 911 dispatch centers, user's physician, and user's listed family members

Business Plan

- Proposed technology to be **marketed** to Apple, Android, and other smart watch manufacturers
  - **Apple would be ideal**
  - Current ECG system is FDA approved

- The validated algorithm and data system will be presented to various companies as a means to improve their pre-existing technology

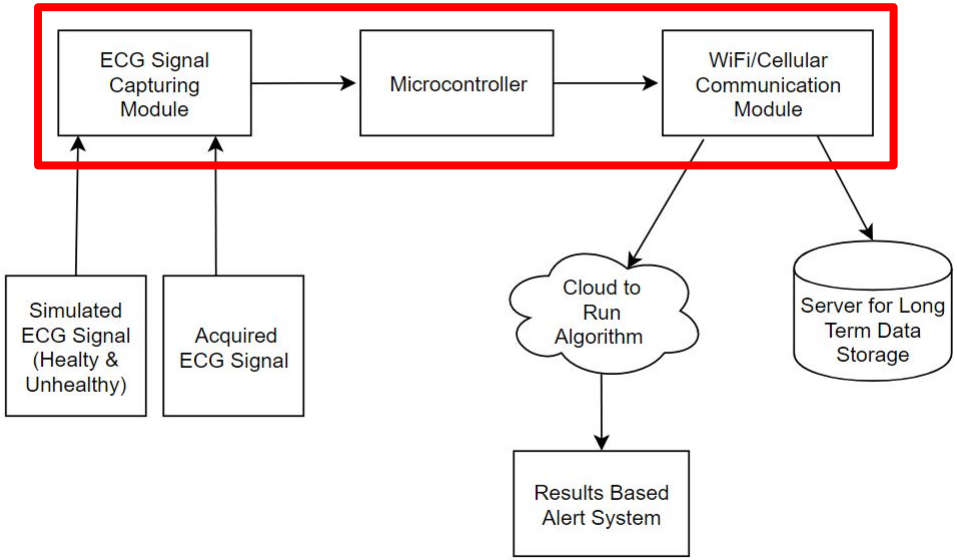
- This approach will allow for the methodology to reach the greatest amount of users if integrated into popular ecosystems

Apple Logo
https://www.freepik.com/free-icon/apple-logo_748451.htm

Android Logo
https://www.freepik.com/free-icon/android-logo_733035.htm

Business Plan - Example for Apple

- The Apple Watch Series 4 already has the technology **boxed in red** and over 20 million devices with customers
- The algorithm will be marketed as a software extension to the Apple Watch environment
- This will allow for the algorithm to reach the greatest population of beneficiaries, leading to the most positive impact



Expected Impact

- **If the algorithm is validated and implemented across all Apple Watches:**
  - The 24 million Apple Watch users will be reached by a heart characterization system
  - Data will be acquired for all of the users, if the option is selected
  - Will lead to a higher understanding of SCA and other heart anomalies

Conclusion

- **With the new algorithm, we hope to achieve:**
  - A continuous and more accurate smart ECG monitor
  - To have the first SCA detection process to be implemented in smartwatches
  - Saving hundreds of lives from SCA

Questions?

References

Journals:

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2.) Raka, Annmarie, et al. “Computational Algorithms Underlying the Time-Based Detection of Sudden Cardiac Arrest via Electrocardiographic Markers.” Applied Sciences, vol. 7, no. 9, 2017, p. 954., doi:10.3390/app7090954.

3.) De Luna, A.B.; Coumel, P.; Leclercq, J.F. Ambulatory sudden cardiac death: Mechanisms of production of fatal arrhythmia on the basis of data from 157 cases. Am. Heart J. 1989, 117, 151–159.

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Websites:

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6.) https://www.investors.com/news/technology/click/apple-watch-sales-mystery/

7.) https://www.jems.com/articles/2018/07/the-ibeat-is-a-smart-watch-but-it-can-t-save-your-life.html

References

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Available: https://wearablesensing.com/files/Matthews%20et%20al_2005_The%20invisible%20electrode%20-%20zero%20prep%20time,%20ultra%20low%20capacitive%20sensing.pdf

9) https://www.egr.msu.edu/classes/ece445/mason/Files/7-BioAmps.pdf

10.) https://www.mouser.com/ProductDetail/Microchip-Technology-Atmel/ATMEGA1281V-8AU?qs=2nyfZ6BV3oicD0KJ61yyng%3D%3D

11.) https://www.researchgate.net/publication/226838627_A_wearable_wireless_ECG_sensor_A_design_with_a_minimal_number_of_parts

References

Images:

1.) http://www.eliasworldmedia.com/HewlettPackardEnterprise/

2.) https://www.cdc.gov/heartdisease/facts.htm

3.) https://www.apple.com/apple-watch-series-4/health/

4.) https://www.freepik.com/free-icon/apple-logo_748451.htm

5.) https://www.freepik.com/free-icon/android-logo_733035.htm

6.)https://wearablesensing.com/files/Matthews%20et%20al_2005_The%20invisible%20electrode%20-%20zero%20prep%20time,%20ultra%20low%20capacitive%20sensing.pdf

7) https://en.wikipedia.org/wiki/Heart#/media

8) http://www.michiganradio.org/post/michigan-state-name

9) https://www.mouser.com/ProductDetail/Microchip-Technology-Atmel/ATMEGA1281V

10) https://wearablesensing.com/files

11) http://www.rainsun.com/wp-content/uploads/