Sensor, Signal and Information Processing (SenSIP) Center and NSF Industry Consortium (I/UCRC)

School of Electrical, Computer and Energy Engineering
Ira A. Fulton Schools of Engineering

AJDSP interfaces for Real-time Sensing and Physiological Monitoring

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SenSIP – A site of the Net-Centric I/UCRC

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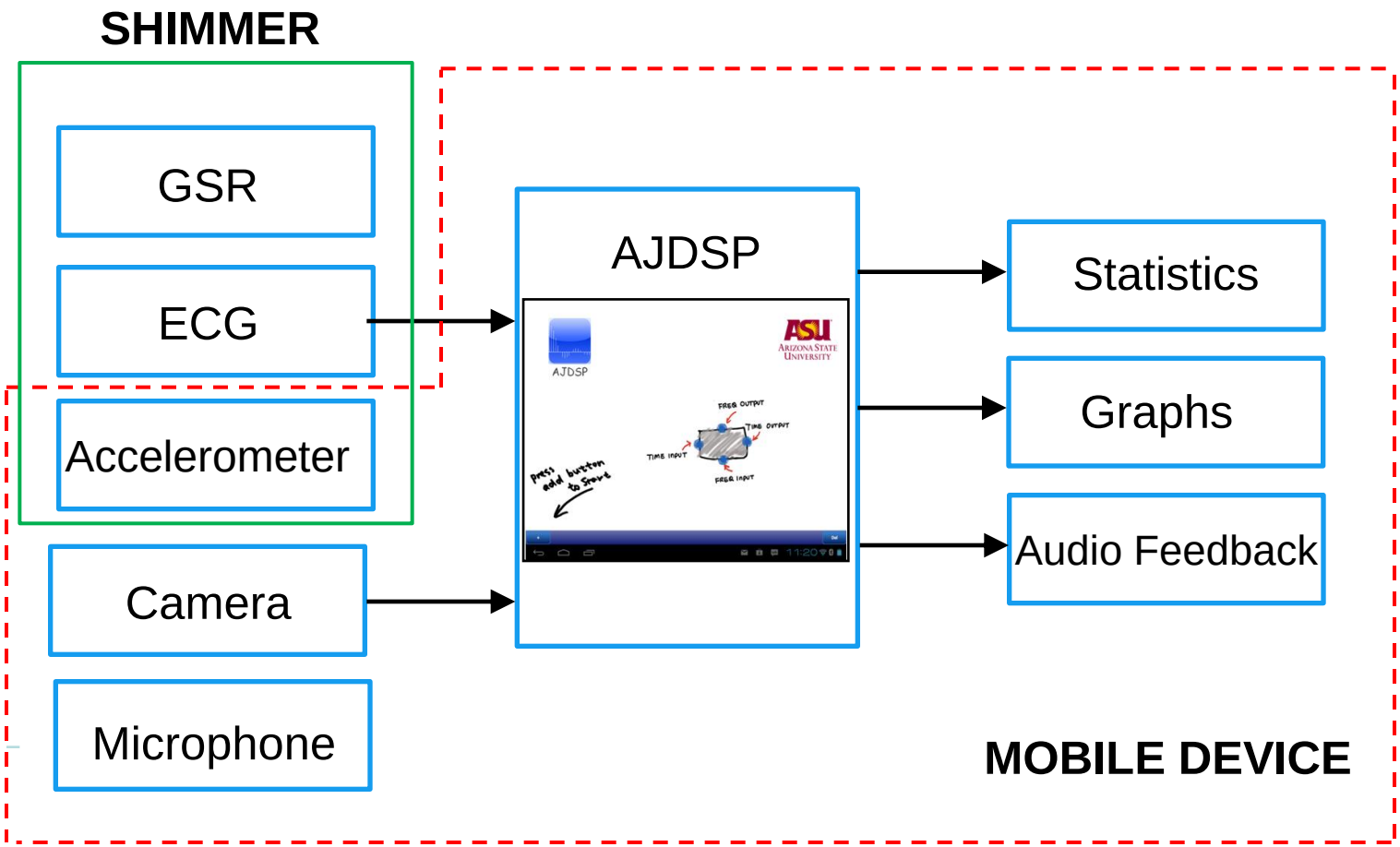
Motivation

- Exploit the interactivity of Android mobile devices to complement DSP curriculum.
- Interface on-board and external sensors to relate concepts in wireless sensor networks and DSP to real-world applications.
- Build an intuitive scientific paradigm to:
  - Demonstrate process of extracting application specific features.
  - Present examples of applications in mobile healthcare.

The AJDSP App

- Is an Android DSP educational application.
- Consists of a graphical programming environment to enable simulation and visualization of DSP concepts.
- Interfaces with both on-board and external wireless sensors.
- Supports signal processing topics such as: filter design, convolution, multirate signal processing, the FFT and discrete wavelet transform.

Overview


SHIMMER
GSR
ECG
Accelerometer
Camera
Microphone
AJDSP
Statistics
Graphs
Audio Feedback
MOBILE DEVICE

SHIMMER Sensor Platform

- An on-board microcontroller.
- Bluetooth communication.
- Integrated accelerometer for activity monitoring.
- Connection to daughterboard sensors with kinematic, physiological and ambient sensing functionalities.

SHIMMER - Sensing Health with Intelligence, Modularity, Mobility and Experimental Reusability

AJDSP Sensor Block Functionalities

- Real-time data streaming from Shimmer-based ECG and GSR sensors and accelerometers.
- Data acquisition from on-board accelerometer, microphone and camera.
- Estimate basic parameters such as: heart beat rate, blood pressure, oxygen saturation and skin conductance.
- Feature extraction: statistics (mean, variance, RMS etc.), QRS complex, HRV and R-R interval.
- Time-frequency spectra visualization..

Applications in Development

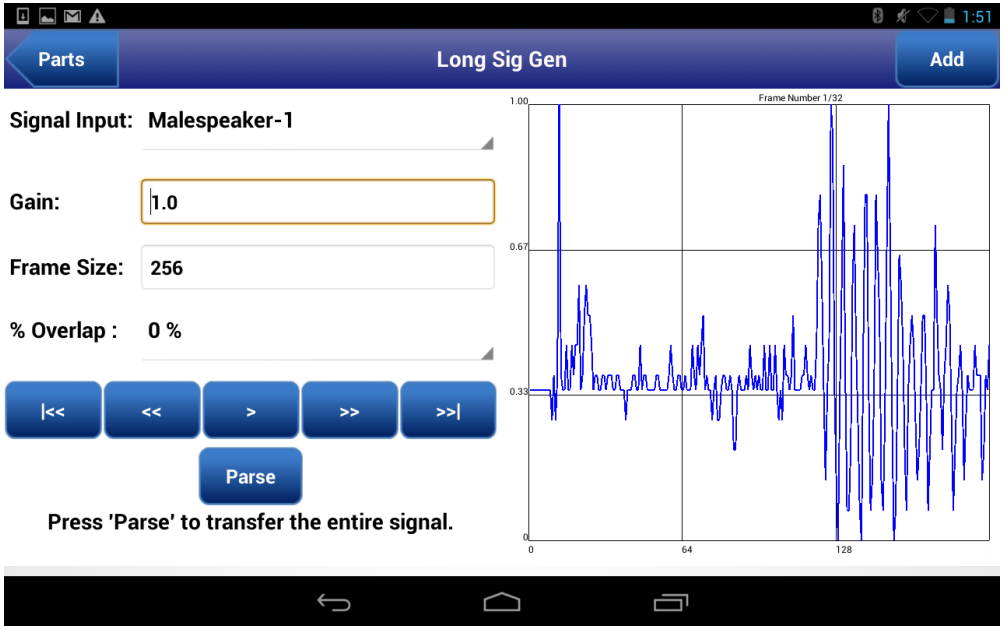
- **Camera**
  - Heart Rate estimation by extracting the Photoplethysmogram (PPG) signal.
- **Accelerometer**
  - Step counter and estimation of walking, standing and running durations using wavelets.
- **ECG**
  - Estimating heart rate and extracting features such as R-R interval, HRV, Pulse Transit time etc.
- **GSR**
  - Extract features such as mean and standard deviation of Skin conductance level (SCL) and number of startle responses.
  - Combine various physiological data to detect stress.

Sensor Signal Acquisition Blocks

- Long Signal Generator
- Sound Recorder
- Accelerometer
  - On-board
  - Shimmer
- Biosignal Generator
  - Open source data
  - Shimmer

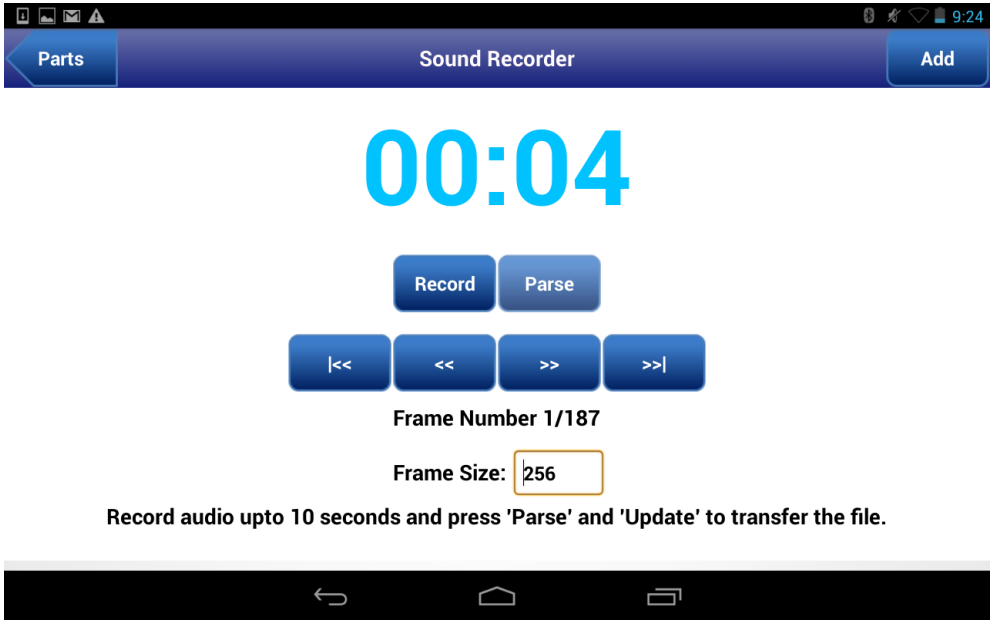
Long Signal Generator

- Consists of pre-recorded audio/noise signals.
- Data is processed and visualized as frames.
- Voiced and unvoiced segments of speech can be observed.
- Frame size, gain, and amount of overlap can be controlled.



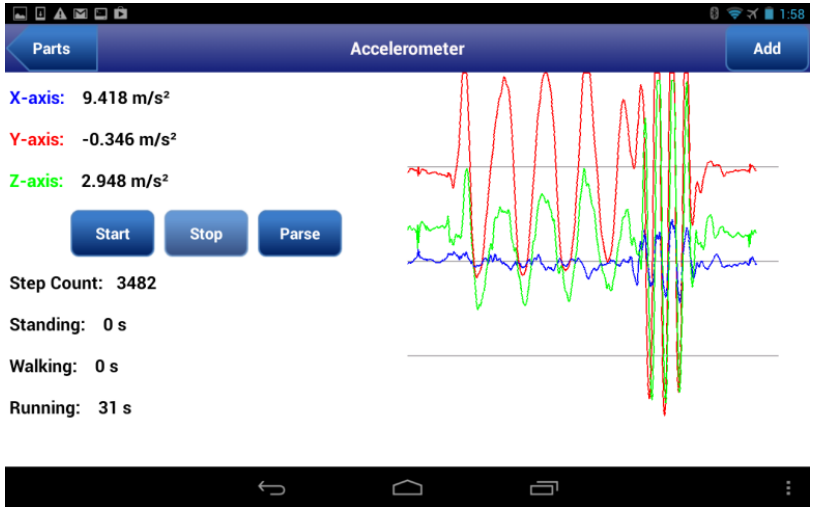
Sound Recorder

- Acquire data from on-board microphone.
- Record audio upto 10 seconds.
- Frame size can be manipulated.

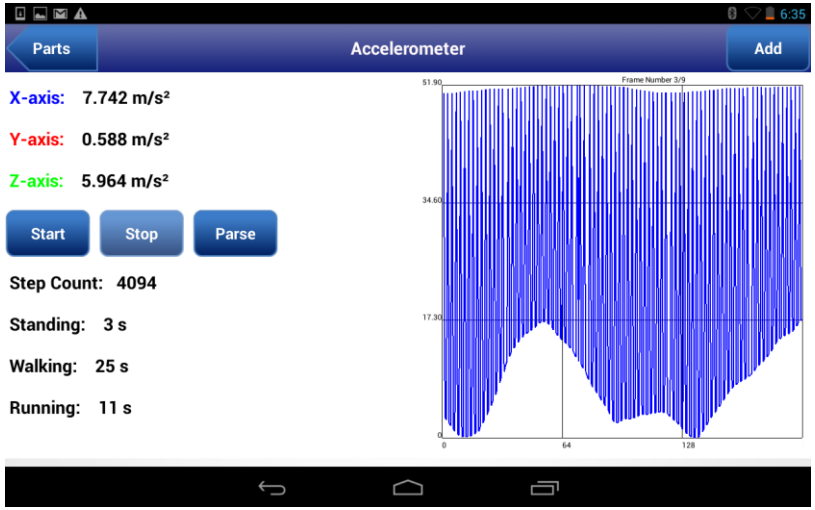


Accelerometer

- X, Y and Z-axis data can be streamed from on-board accelerometer.
- Once acquired, signal magnitude frames are visualized.
- Transitions in the signal based on device orientation and movement can be observed.



Accelerometer step counter

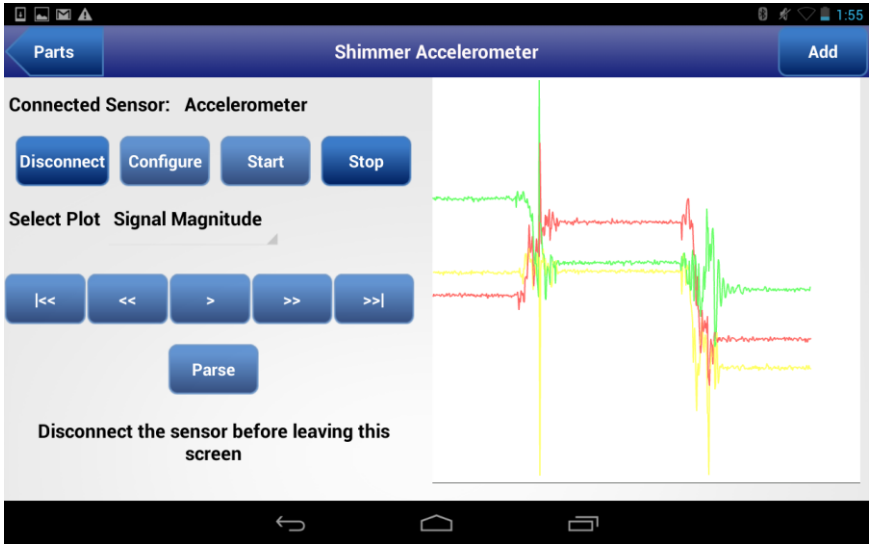


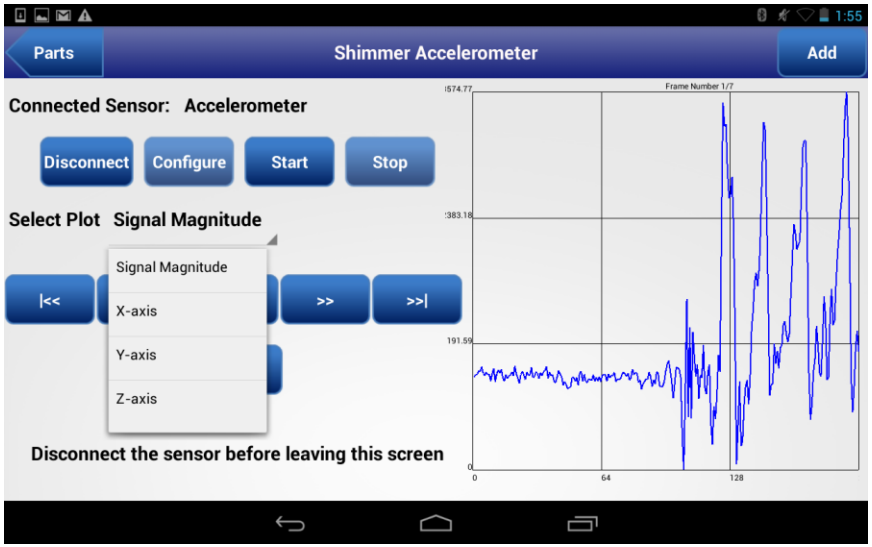
Step Counter using on-board Accelerometer:

- Compute signal vector magnitude (SVM) from the X, Y and Z-axis measurements.
- Smoothen the signal using Daubechies04 wavelets.
- Detect hills and calculate threshold by processing windows of 100 samples.
- Iterate over the entire signal to detect peaks above the threshold and increment the step count.
- Classify activity mode:
  - Standing – no steps for more than 2 seconds.
  - Walking – 1 to 3 steps per second.
  - Running – more than 3 steps per second.

Shimmer Accelerometer

- Establish connection to the Shimmer sensor.
- Sensor is configured and data is transmitted to the device through Bluetooth.





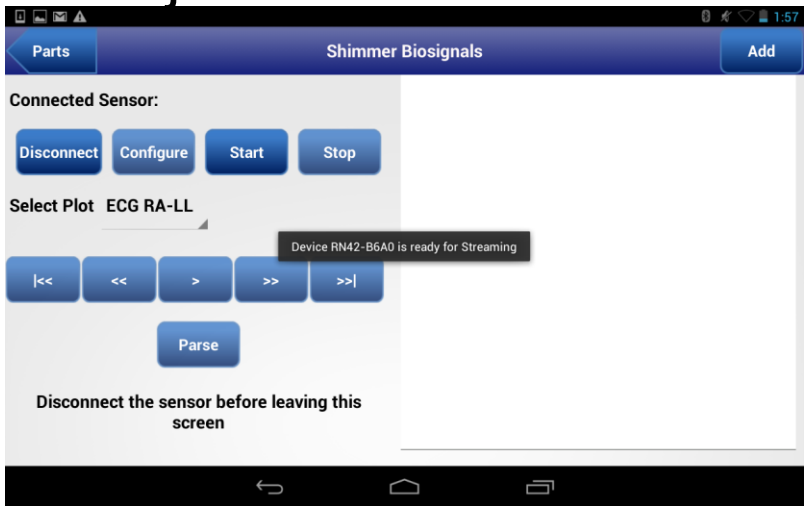
- Acquired data can be processed using other AJDSP blocks.

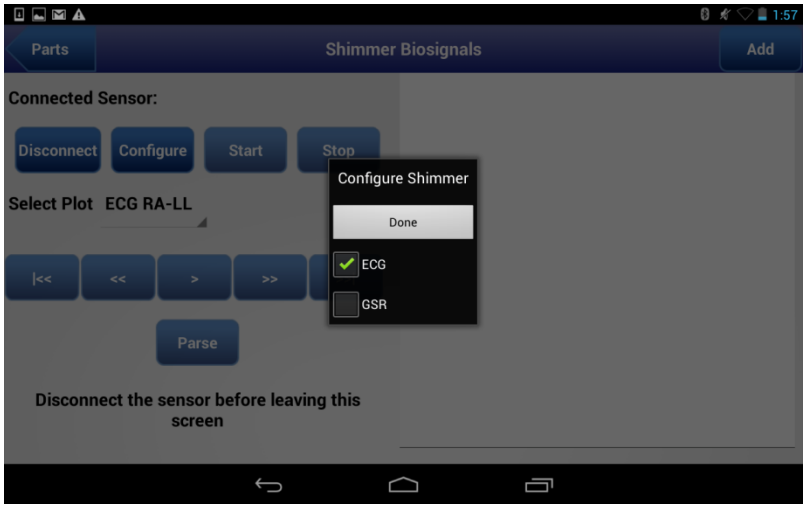
Biosignal Generator

- Obtaining measurements from every subject for a laboratory exercise is cumbersome.
- Open source ECG data for normal and abnormal health conditions are pre-loaded.
- Signals characteristics are visualized and related to medical conditions.

Shimmer ECG/GSR Generator

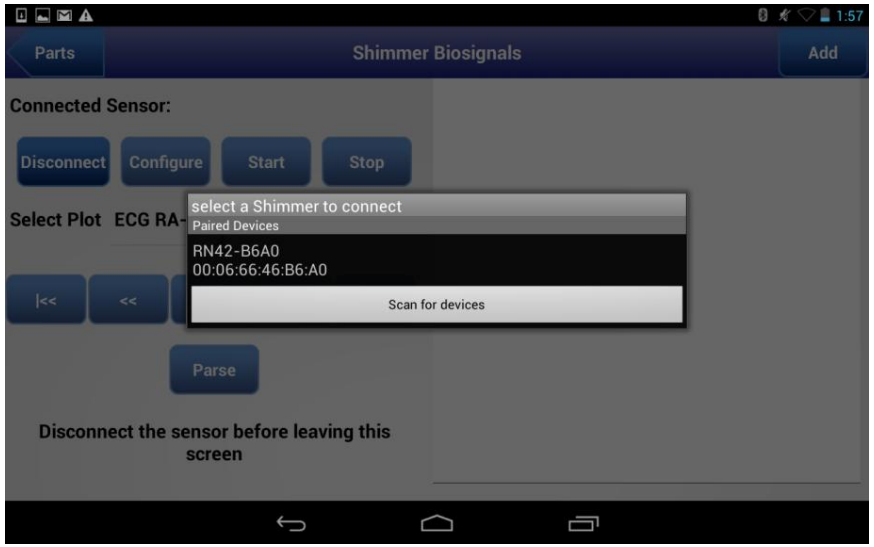
- Connection to shimmer ECG/GSR sensors is made.
- Sensors are configured and ECG signals in either Lead I, II or III configurations is streamed.
- Sensors are placed on the chest/wrist using straps.
- Electrodes are used to make a contact between the subject and the sensor.





Shimmer ECG/GSR Generator

- Data is streamed into the app and an there exists an option to observe frames of either lead I (LA-LL), lead II (RA-LL) or the skin response signal.
- Sensor is disconnected before navigating to the workspace to process the acquired data.



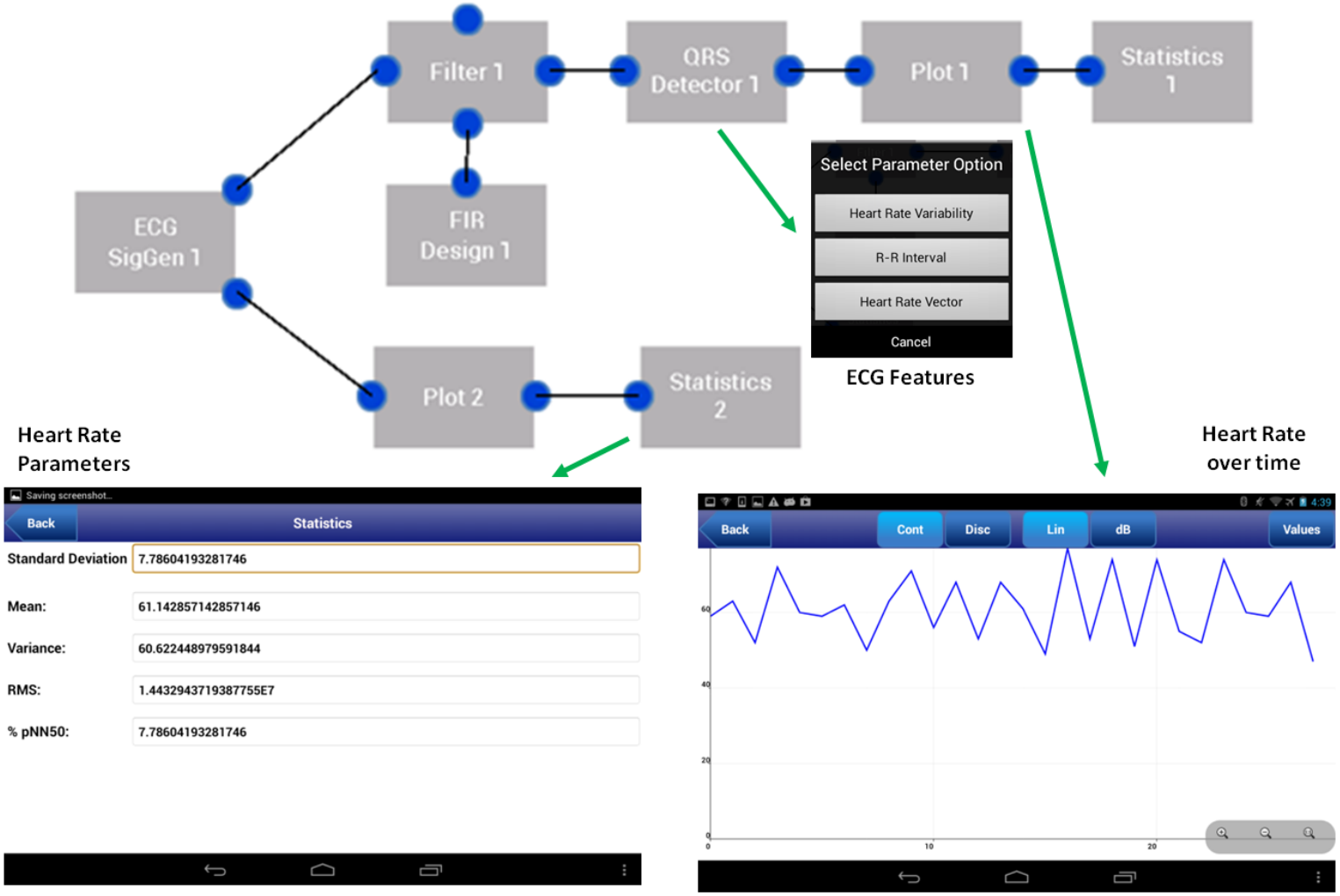
Signal Processing Blocks

- ECG Feature Extraction
- Discrete Wavelet Transform
- Inverse Wavelet Transform

ECG Feature Extraction

- R-peaks of the QRS complexes are detected using multiresolution wavelet transform.
- Daubechies Wavelets are used as they most closely represent an ecg waveform.
- Features such as R-R interval, Heart Rate Vector, Heart Rate Variability are generated.
- Other features include: root mean square (RMS) value of the differences between successive R-R intervals, and percentage of heat beat intervals with a successive R-R difference in interval greater than 50ms (pNN50).
- Based on these features, the signals can be related to health conditions.

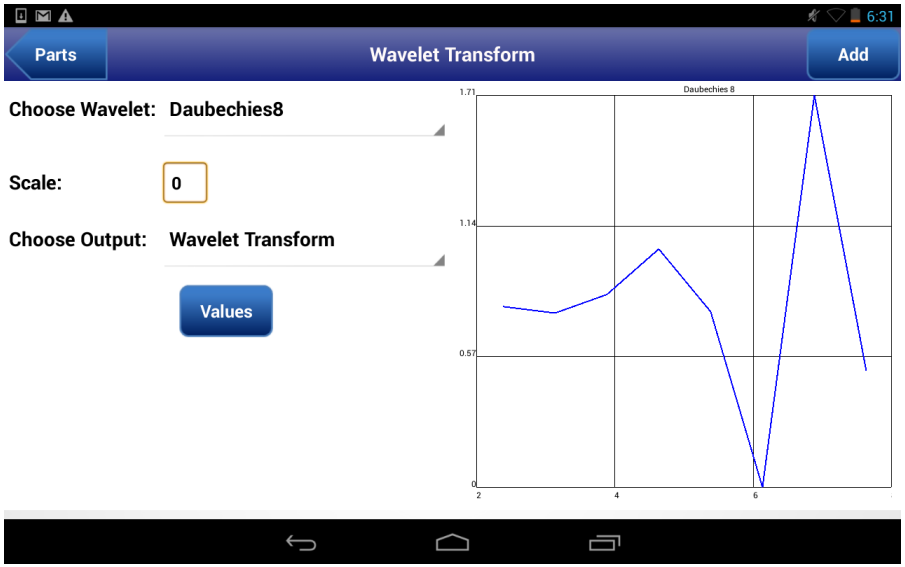
Example: ECG Feature Extraction

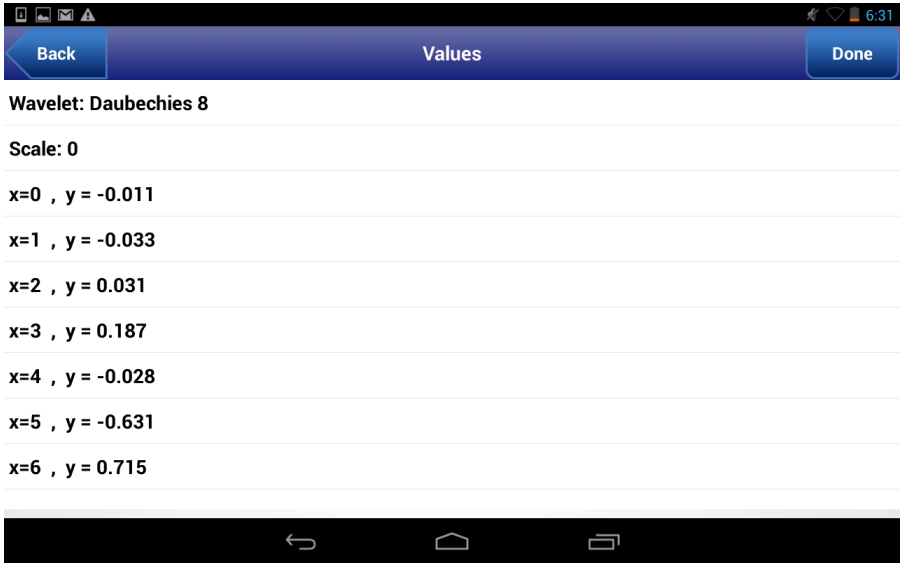


Wavelet Transform

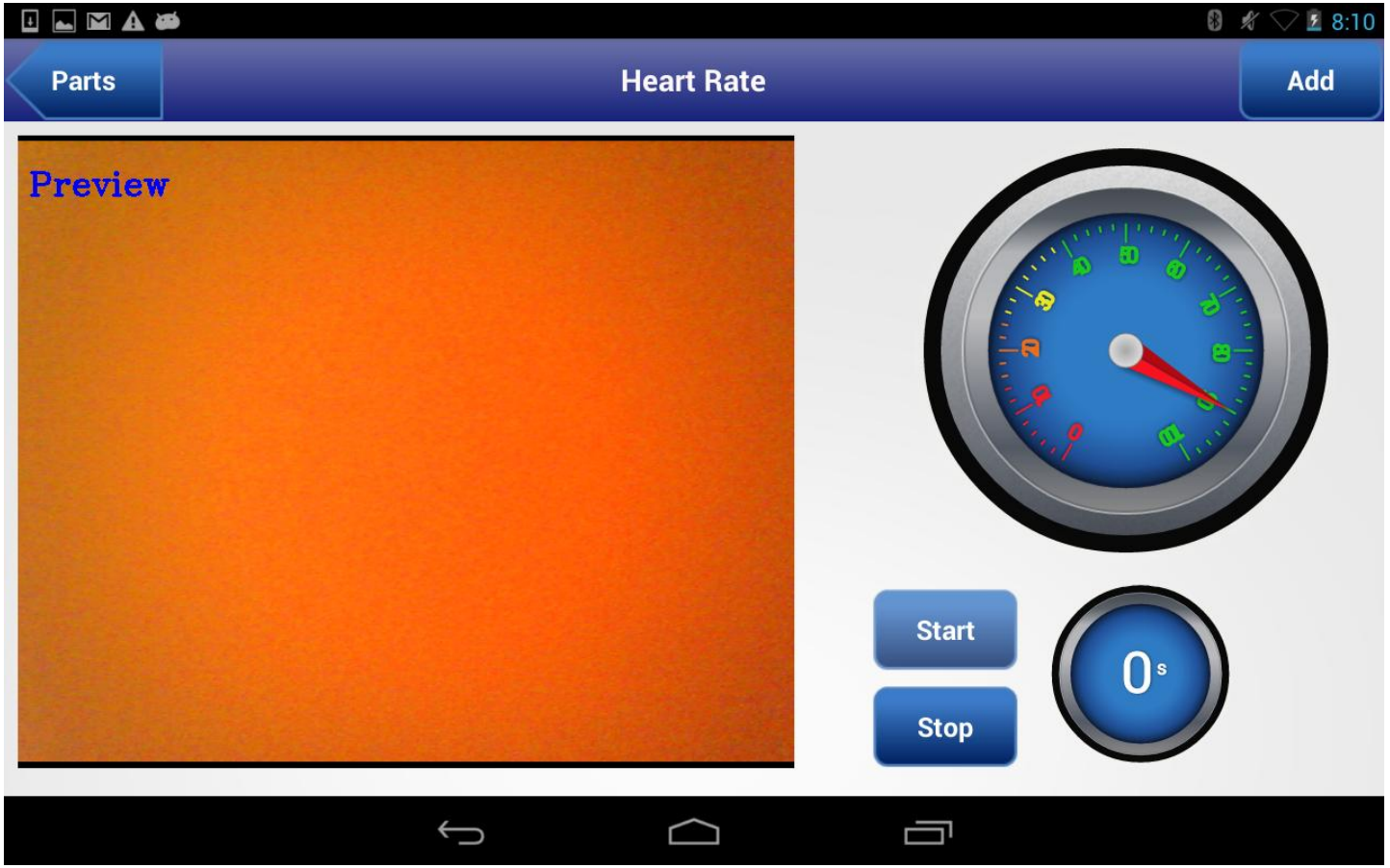
- The discrete wavelet transform (DWT) block uses a dyadic transformation to produce scaling (low-pass) coefficients and detail (high pass) coefficients.
- Waveforms of the various wavelets from Haar, Daubechies 4, 6 and 8, Legendre 2, 4 and 6, and Coiflet 6 can be observed.
- The appropriate wavelet for a specific application can be selected.
- The number of multiresolution levels/scales to decompose the signal can be configured.
- The output signal of the DWT block can be selected as: scaling/detail coeffs or the entire transformed signal

Wavelet Transform





PPG Heart Meter



Heart Beat Rate using Photoplethysmogram (PPG):

- Record a video by placing the finger tip on the lens of the device camera.
- Extract the PPG signal using pixel brightness of individual video frames.
- Estimate Heart Beat Rate by detecting the number of peaks within a time window.

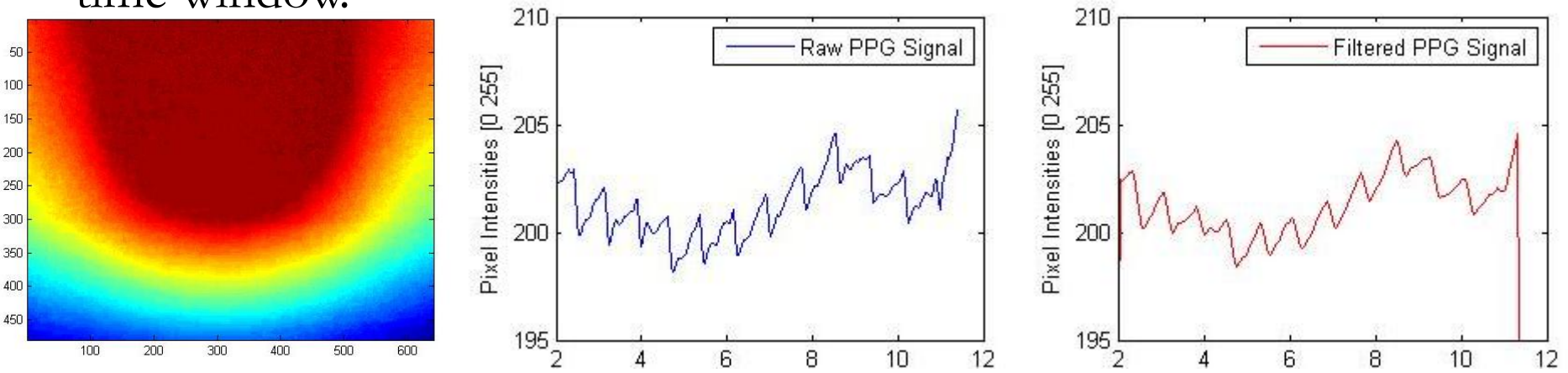


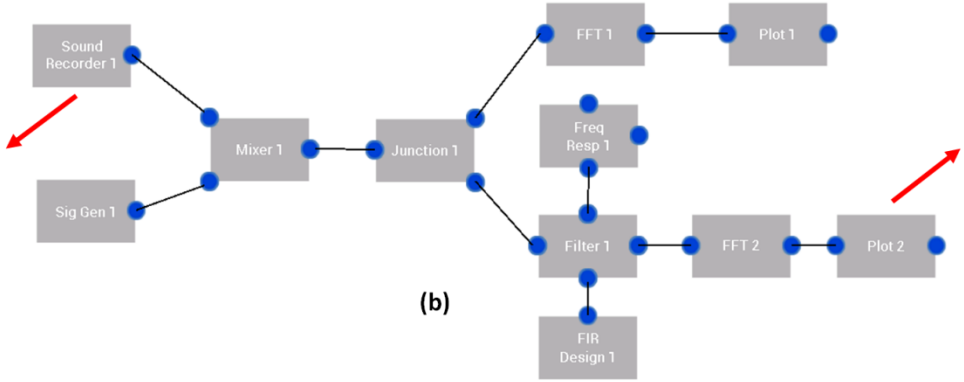
Fig: Sample input video frame and the corresponding plot of the PPG signal with time.

Laboratory Exercises Developed

- To demonstrate a wireless DSP sensor system, understand remote data acquisition, and to learn simple concepts about accelerometers and their role in context aware applications.
- To demonstrate a non-invasive health monitoring system using the camera to extract a physiological signal.
- To understand ECG signal characteristics, parameter estimation, and filtering.

Example: Audio Filtering Simulation

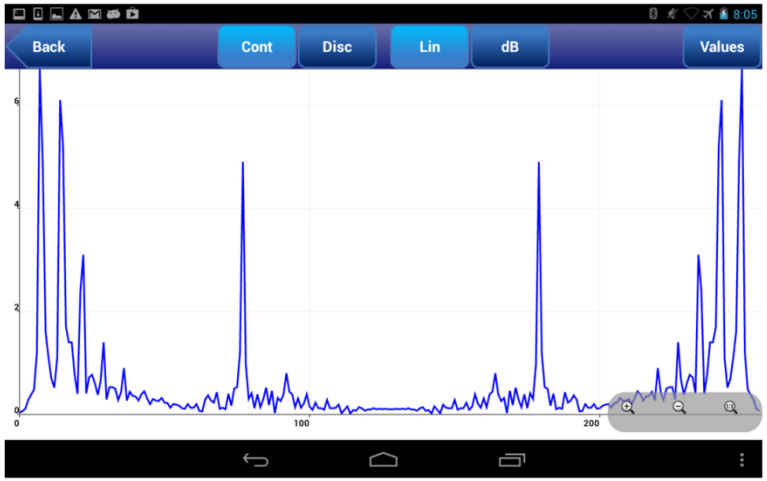
(a)



(b)

(c)

Noisy Signal



(d)

De-noised Signal

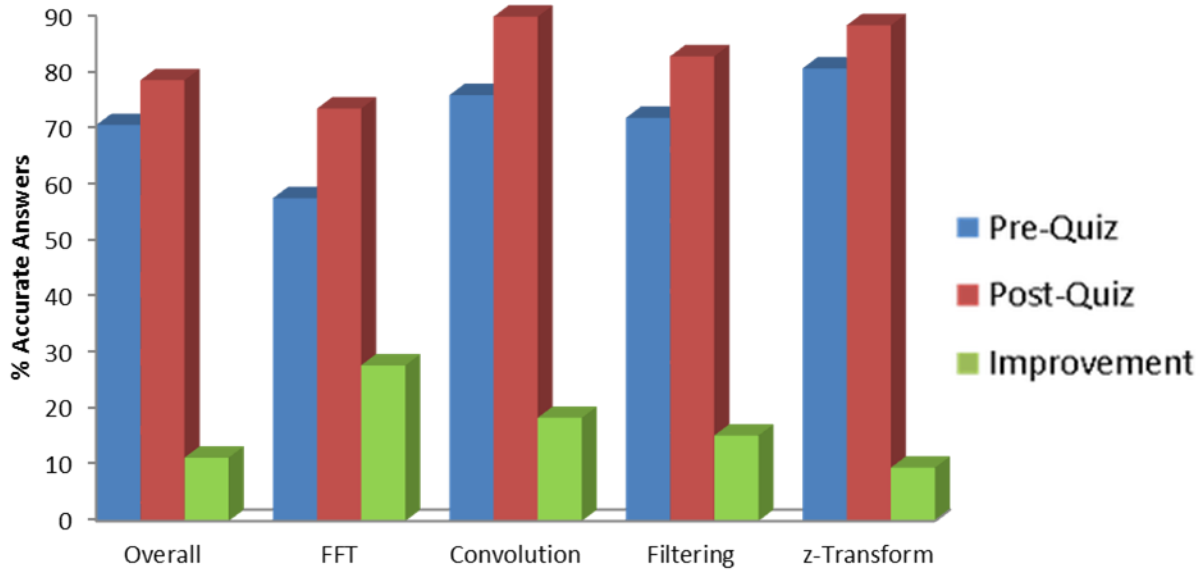
(e)

Assessments and Results

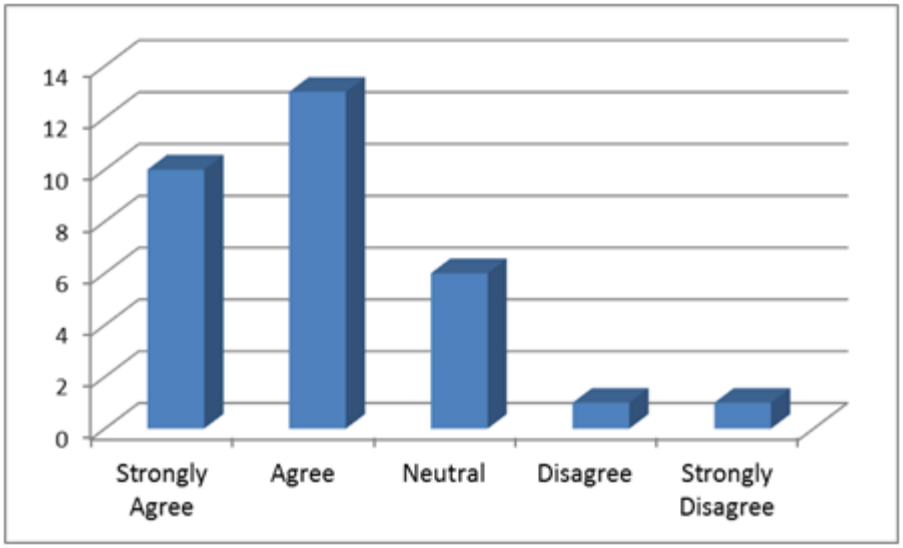
- Preliminary assessments of AJDSP involved two workshops:
  - Graduate student workshop was to assess the robustness and the accuracy of the software.
  - Undergraduate student workshop was conducted to assess the ability of the application to foster understanding of signal processing concepts.
- Concepts tested in the workshop with the help of exercises consisted of filter design, FFT, *z*-transforms and convolution.
- A total of thirty-three students participated in the assessment workshops

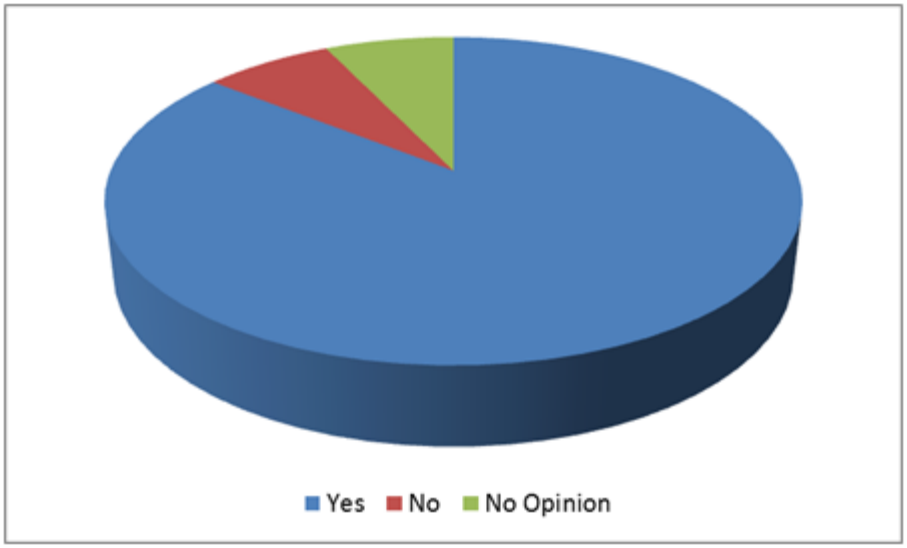
Assessments and Results

- Most students were satisfied with the robustness and speed of the AJDSP app.
- Based on this exercise, an overall improvement in understanding was observed to be about 11 percent.



Assessments and Results





m-Health Applications

- Arrhythmia
- Tachycardia and Bradycardia
- High/Low Blood Pressure
- Mental Stress
- Hypovolemia
- Manage personal health records

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