**Objective**
- The Electrocardiogram (ECG) is a key diagnostic monitor used by clinicians for in-patient and increasingly for out-patients.
- Temporal location of ECG P, Q, R, S and T phases enables many diagnostic decisions:
  - Pulse $\rightarrow$ from R phase spacing
  - Changes in intervals between waves can be indicators of various conditions or identify risks

**Challenges**
- Noise – ECG signals are mV range
- Normal variations in wave form
- Inverted T waves
- Additional phases – Normal conditions, Infants
- Medical conditions: Missing, extra, variant phases

**Dataset**
- ECG training set (33 ECGs) from [www.physionet.org](http://www.physionet.org)
- 4 ECGs: “Non-Invasive Fetal ECG Database”
- 3 ECGs: “Intracardiac Atrial Fibrillation Database”

**Multi-resolution Wavelet Analysis**
- **Overview:**
  - Decompose signals into frequency bands using short length filters to allow for compact support in time
  - Results in a series of detailed and final approximation signals representing various frequency bands of the signal

**Empirical Mode Decomposition**
- **Overview:**
  - EMD selectively uses the signal itself as the decomposition reference.
  - Decomposes signal into a series of Intrinsic Mode Functions (IMF) and a resulting residue
  - Reconstruction is simple through addition of IMFs and final residual

**Detection algorithm**
- Create reconstructions
- For each R phase search for preceding minima $\rightarrow$ P phase
- Do peak search on WLe1 -2 to determine R phase
- Create WLe4 – Approx 5 as signal
- Measure slope trend post S phase and update T phase trend measure
- Based on trend search for maxima/ minima post S phase $\rightarrow$ T phase

**Detection algorithm**
- Search IMF set for lowest IMF with short term energy variation
- Use same method as wavelet

**Fusion Detection Algorithm**
- Calculate R phase candidates per EMD and Wavelet algorithms
- Find R phase candidate sets
- Calculate pulse estimate
- Processed unpaired R phases
  - If adjacent pairs from different algorithm
  - If pulses are close: choose nearest to pulse predicted location otherwise treat as separate R phases
- For separate R phases – Accept if close to predicted pulse location
- Build final set $\rightarrow$ R phases
- Use EMD algorithm $\rightarrow$ Q & S phases
- Find EMD and wavelet algorithm P and T phase candidate sets
- Use average PO gap to identify P wave $\rightarrow$ P phases
- Use average ST gap to identify T wave $\rightarrow$ T phases

**Conclusions**
- None of the errors are common between the EMD and wavelet algorithms enabling fusion algorithm to be developed with improved performance.
- Low false positive (FP) and false negative (FN) rates with fusion technique with false negative errors rates of less than 1% and only 2 false positive errors across almost 1500 phases analyzed
- Wavelet: Shows good rejection of movement artifacts
- P, Q, S, T accuracy highly dependent on the R phase detection accuracy

**Future work**
- Extend algorithm to support block processing for longer duration ECGs
- Include classification models to enhance detection performance
- Test algorithm on longer (duration) ECGs and on ECGs outside training set