I am a “Smart”watch, Smart Enough to Know the Accuracy of My Own Heart Rate Sensor

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RTCPS
Real-Time Cyber Physical Systems

AEIS Lab
Ajou Embedded Intelligent Systems Laboratory

Background : The advent of a new platform, Smartwatch

- In addition to smartphones, many users carry additional platforms like a smart-watch.

- Smartwatches are capable of capturing new sensing information from the human body.
  - Motion sensor, Heart rate sensor

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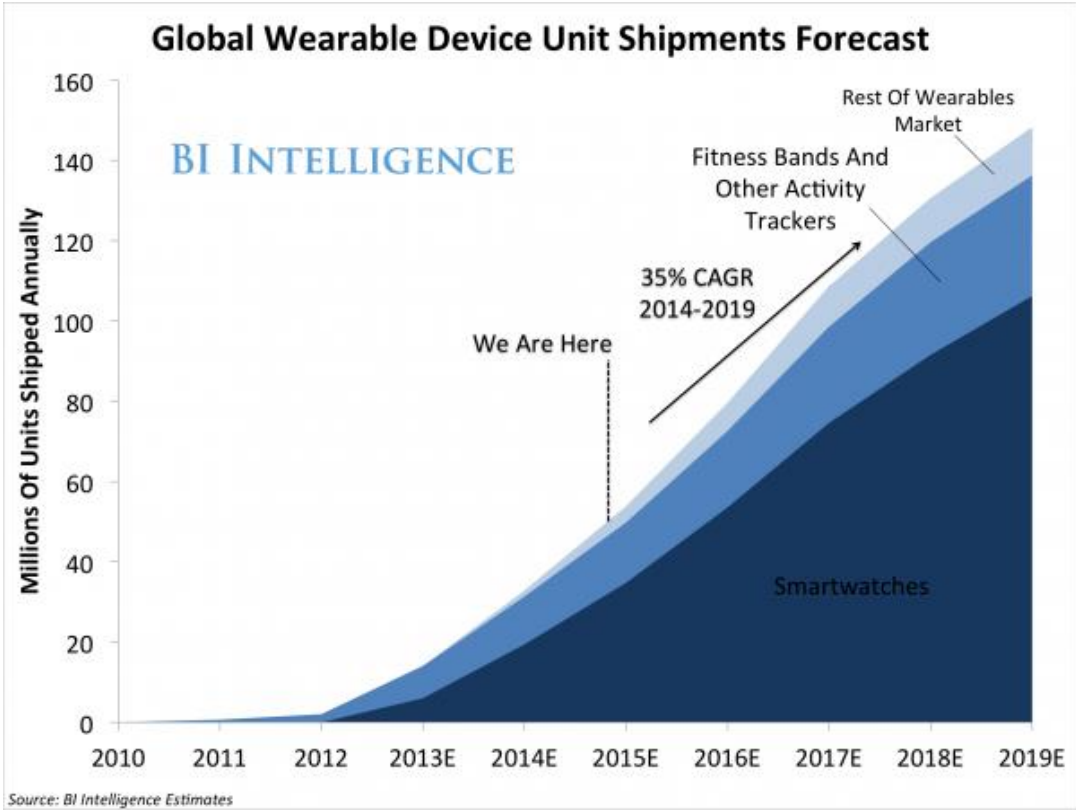
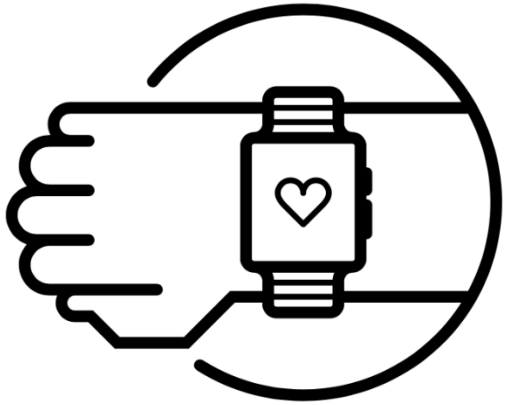


* BI Intelligence, "THE WEARABLES REPORT: Growth trends, consumer attitudes, and why smartwatches will dominate", *Business Insider*, 2015. [Online]. Available: http://www.businessinsider.com/the-wearable-computing-market-report-2014-10.

Sensing on Smartphones and Smartwatches

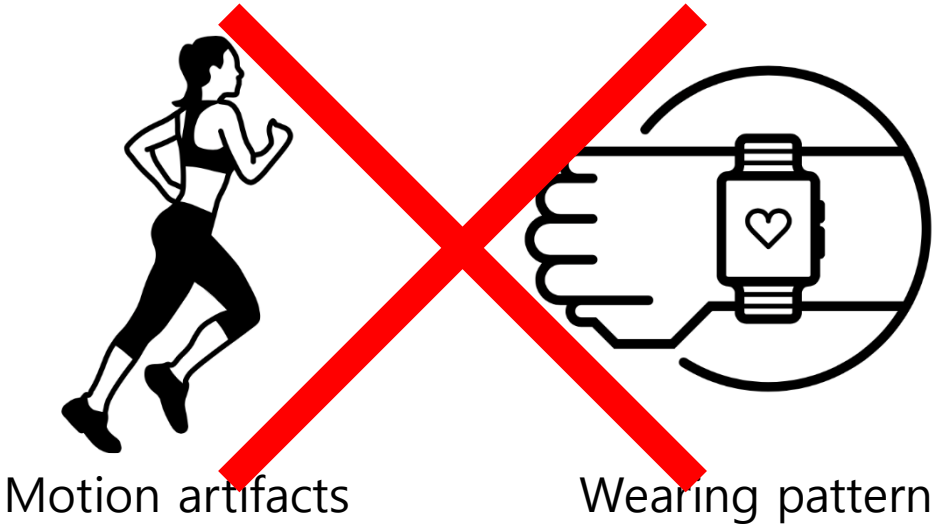


- Smartphone and smartwatches share some common sensor modalities
- Unlike smartphones, smartwatches are attached to a user's skin.
- Sensors on the smart watch open the potential for use in clinical and healthcare applications

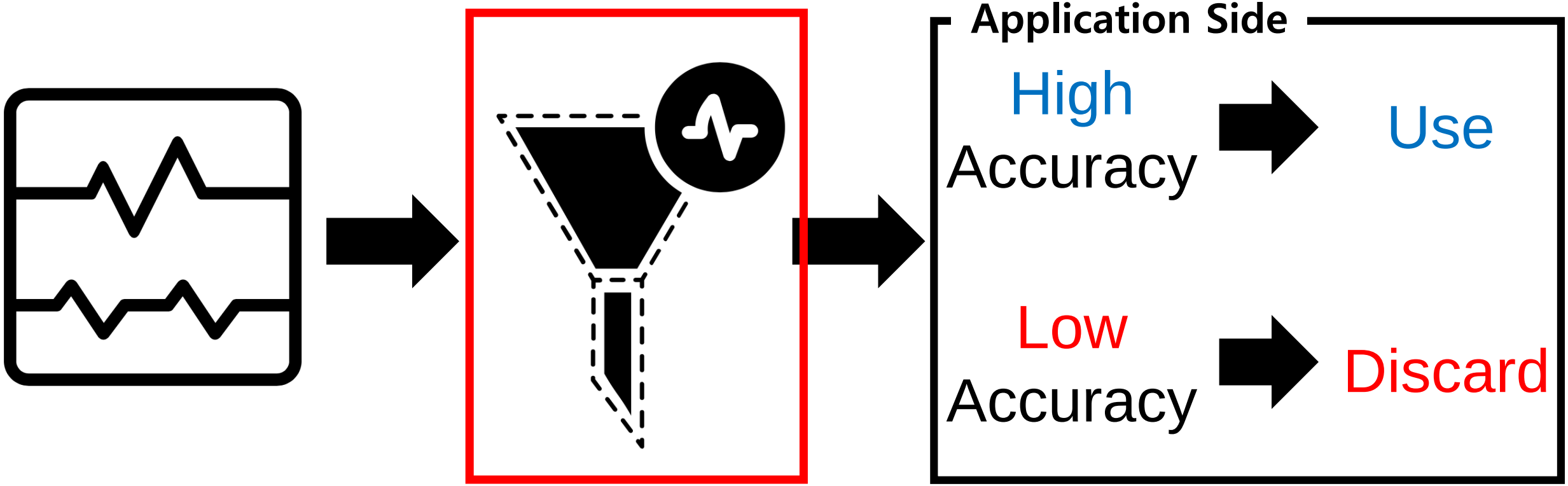
Clinical Application Usage?

- Inaccurate readings can negatively impact the healthcare application's implications on the user's health status.
  - Asthma attacks, stroke, heart attack, …

- Smartwatch vendors admit that the accuracy of heart rate readings may not be high.

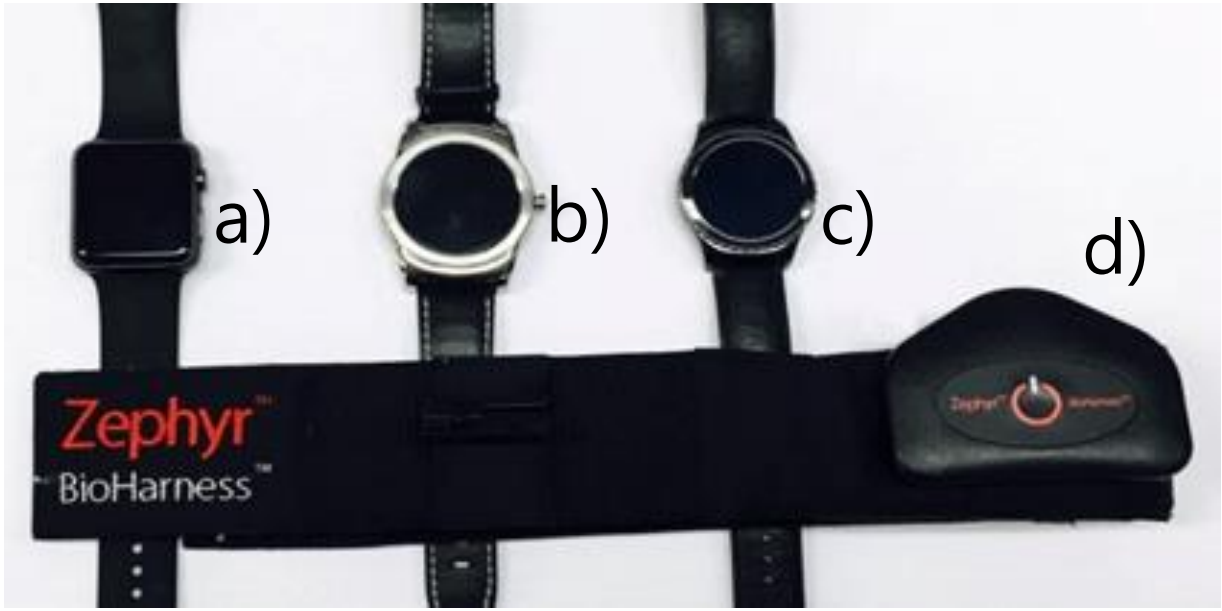


Making the Smartwatch Sensors Reliable!



- If smartwatches can predict the accuracy of the heart rate sensor itself, applications can selectively use the measurement according to the accuracy.

Validation on accelerometer-based approach

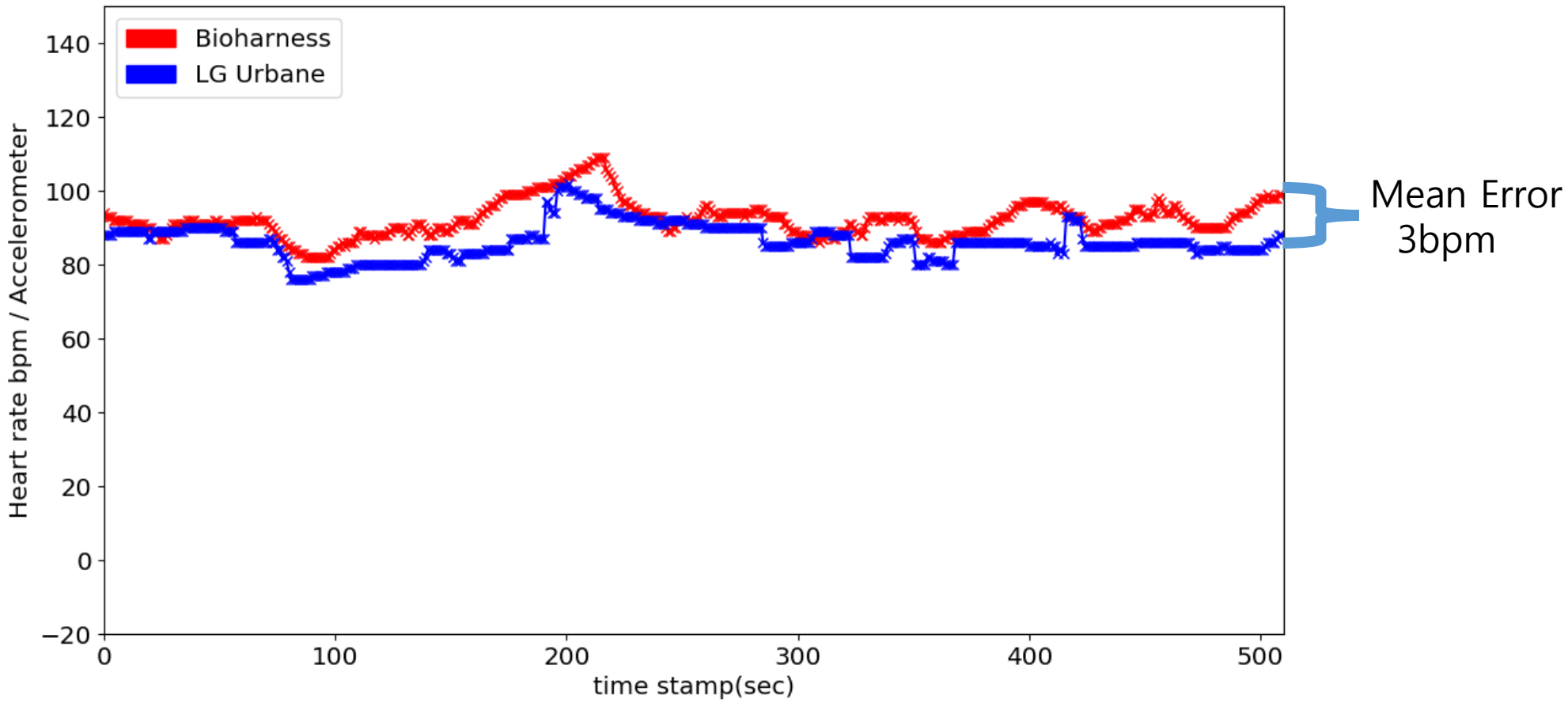


- We use three popular smartwatches to validate accelerometer-based approach.
  - a) Apple watch b) LG Urbane c) Samsung Gear S2
- These smartwatches are compared with ground-truth data from
  - d) Zephyr BioHarness is FDA approved ECG based chest-strap form-factor and able to read heart rate very accurately even when the user walks.

Preliminary Study : Experimental setup

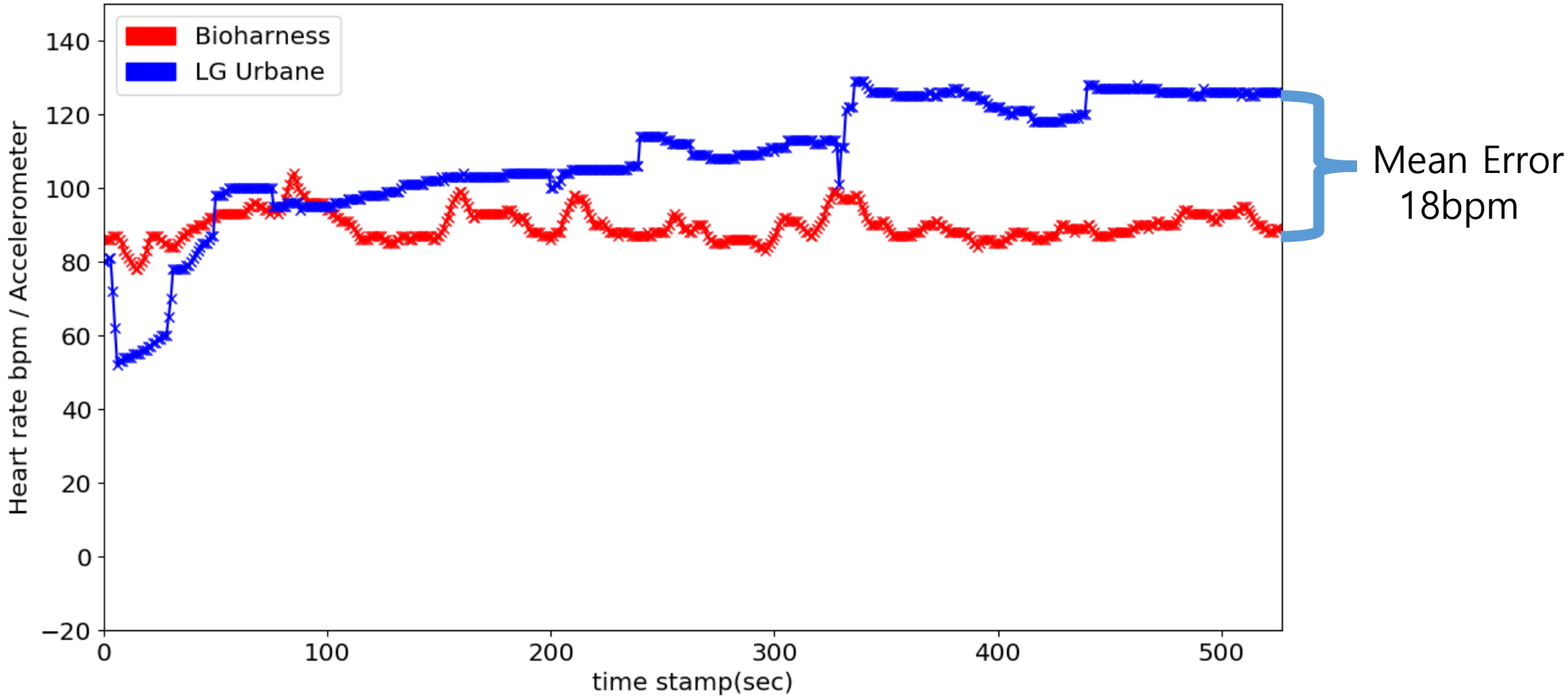
- We ask 4 volunteers (average age of 24; 1 female, 3 male) to naturally walk in a hallway and an open field under fluorescent and day-light conditions while wearing a smartwatch and BioHarness.

Smartwatch Worn Tightly – Less Difference



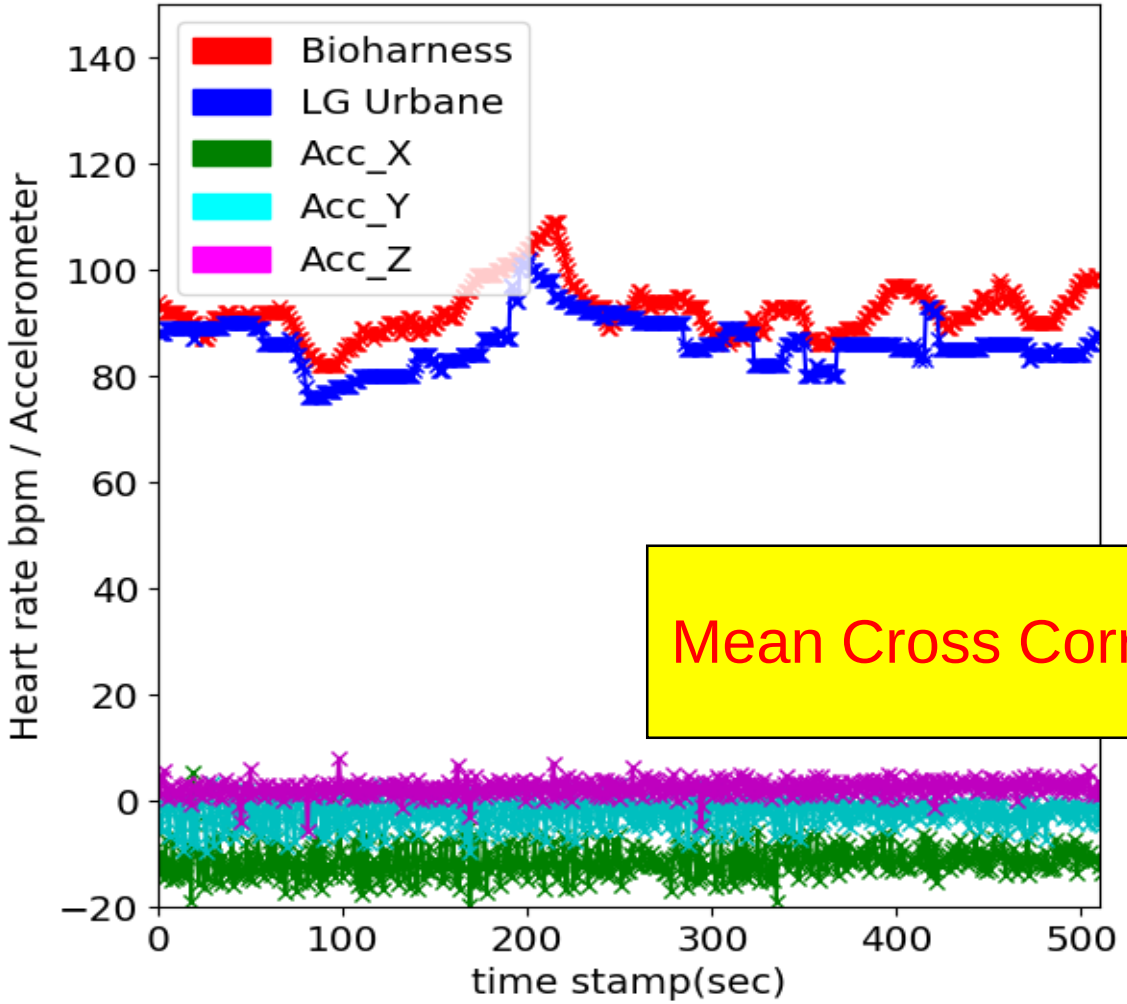
Watch worn tightly – LG Urbane

Smartwatch Worn Loosely – High Difference

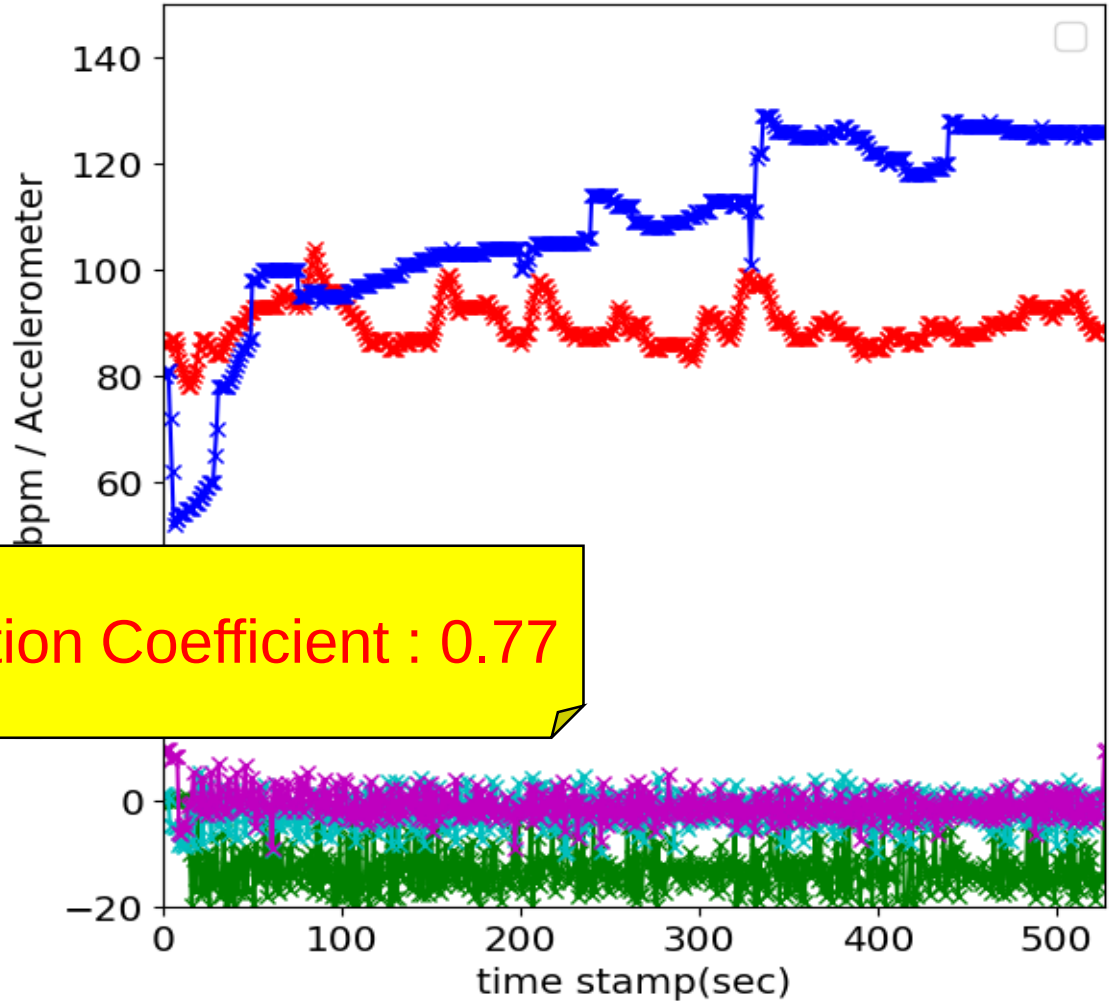


Watch worn loosely – LG Urbane

Accelerometer for Detecting Accuracy?



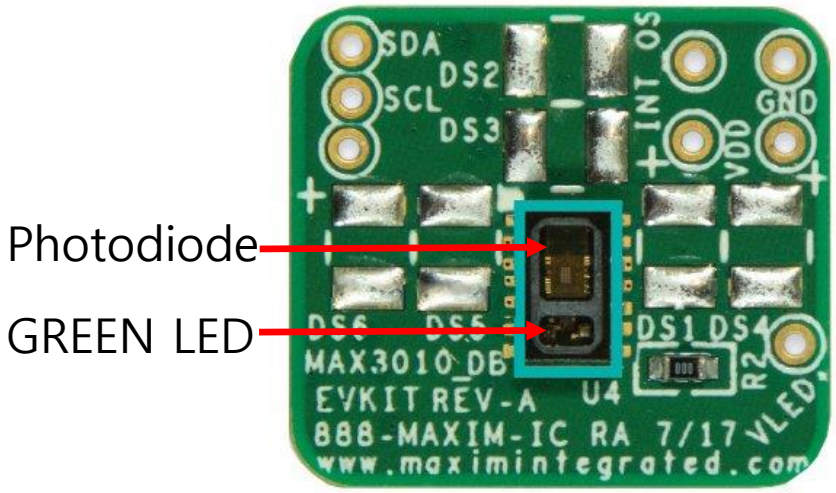
Mean Cross Correlation Coefficient : 0.77



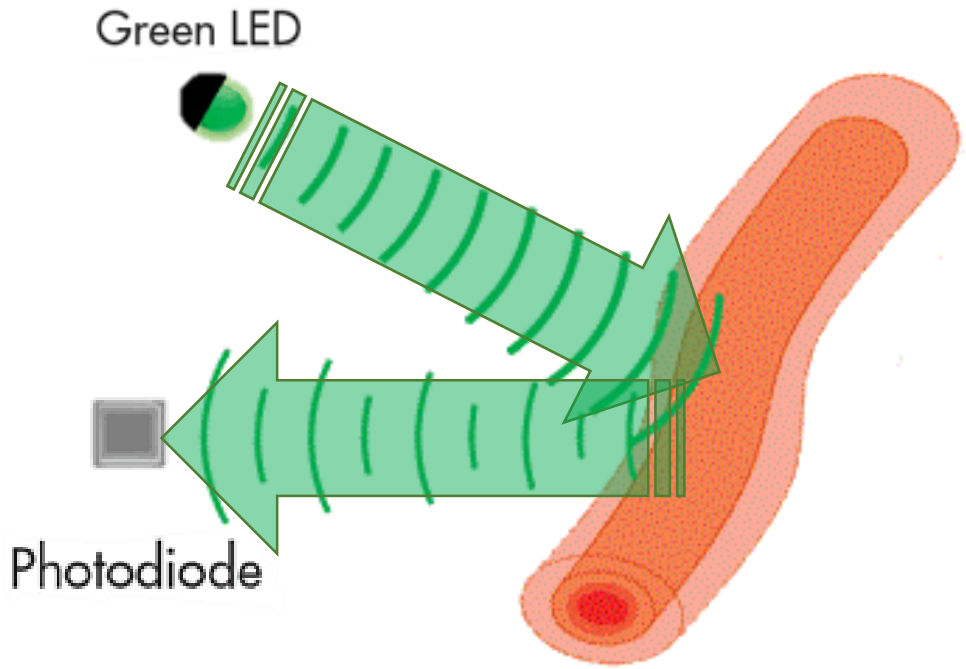
Watch worn tightly– LG Urbane

Watch worn loosely– LG Urbane

Photoplethysmogram (PPG)

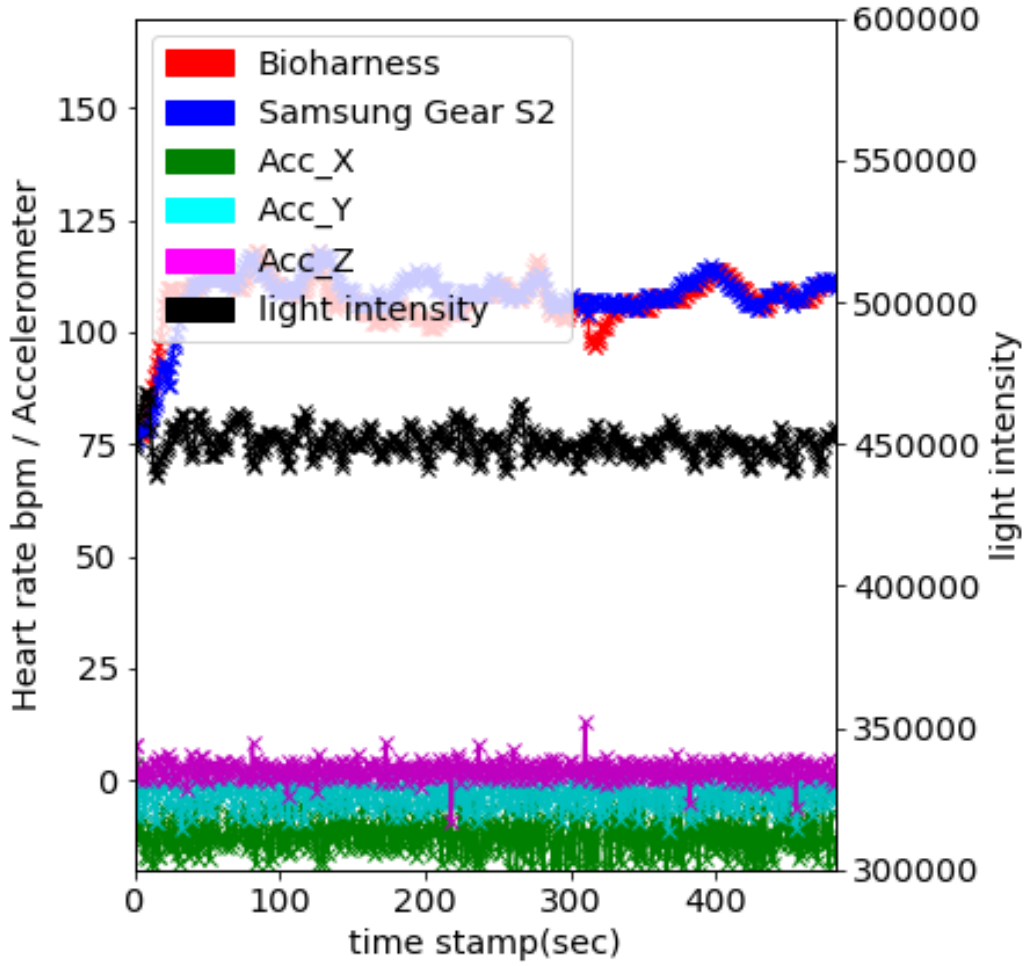


PPG Sensor

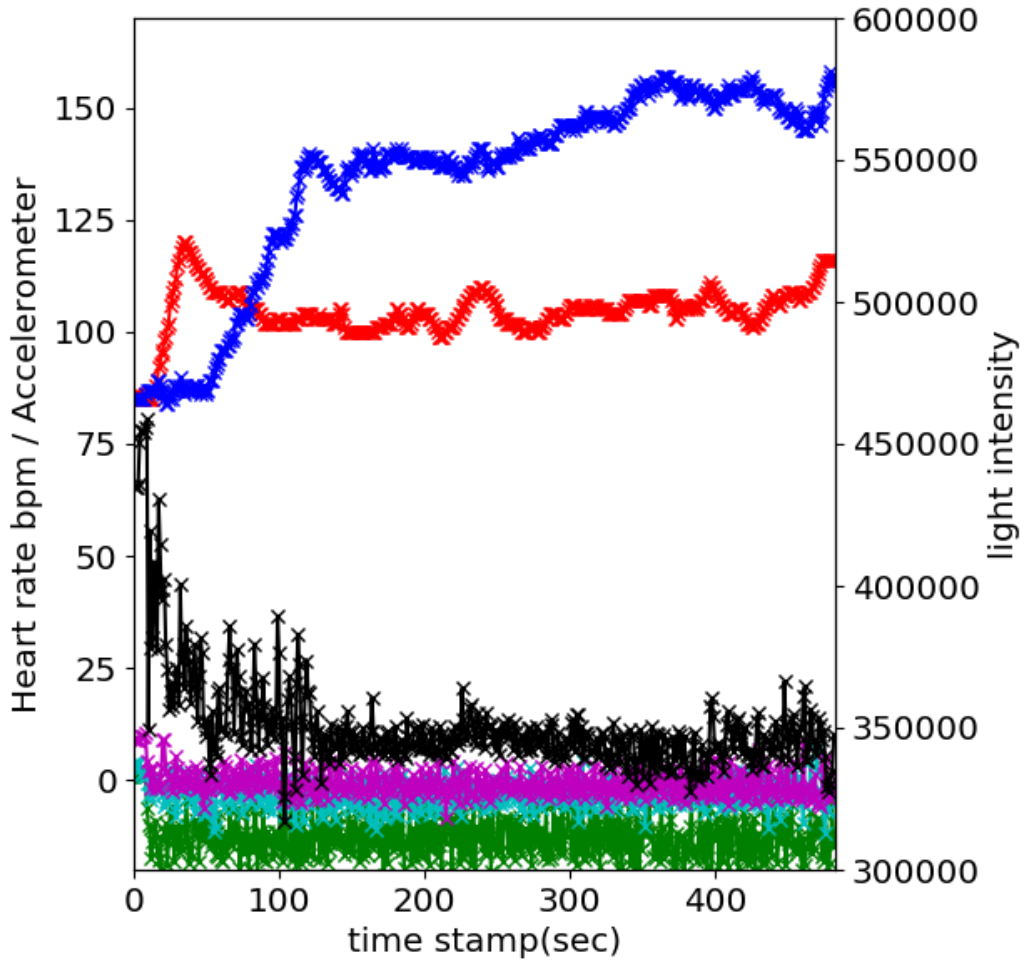


- Uses green LED light emissions and a photodiode capturing reflected light levels from the skin.
- Detects heartrate by measuring the differences in light absorption from the skin.

Light intensity of PPG Sensor



Samsung Gear S2 worn tightly



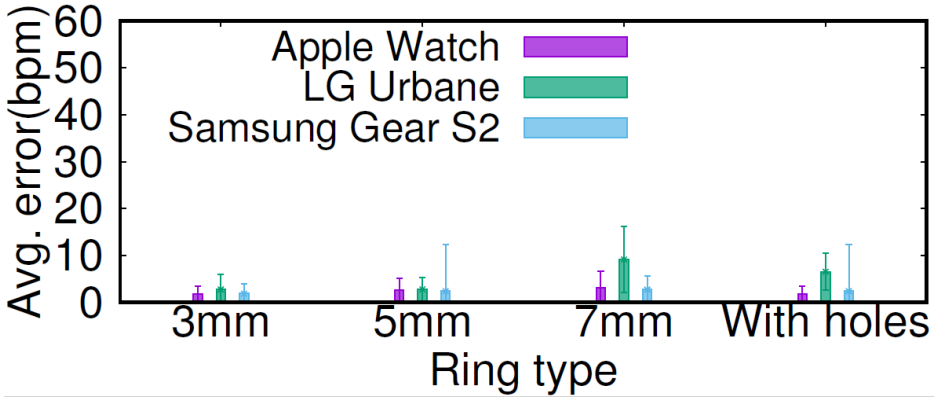
Samsung Gear S2 worn loosely

What factors impact quality of heart rate readings?

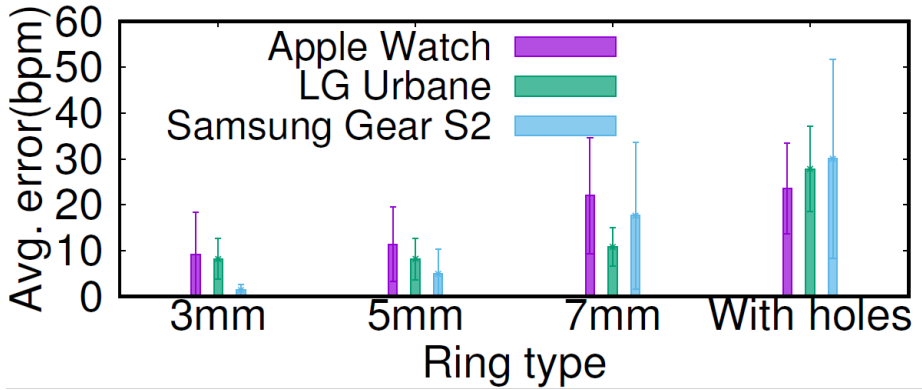
- Absolute value of PPG light intensity vs. Variance of light intensity

- We printed three rings of different heights in order to see what characteristic of light intensity impacts quality of measuring heart rate.

What factors impact quality of heart rate samples?



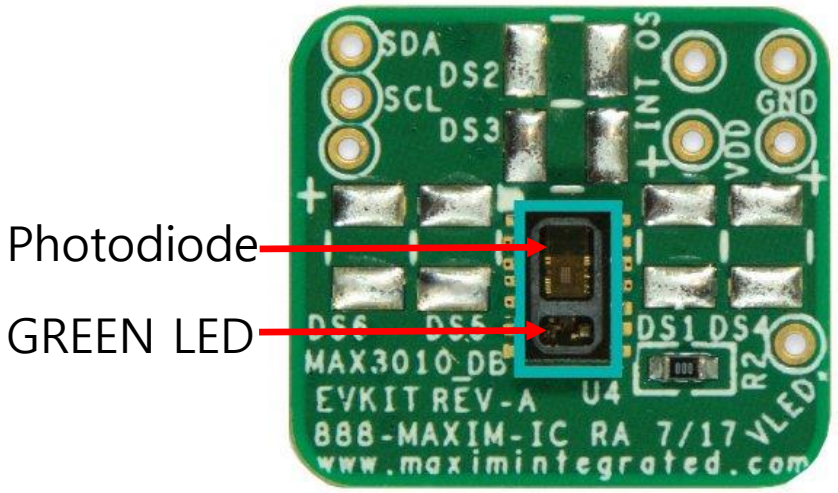
(a) Average heart rate error for standing still



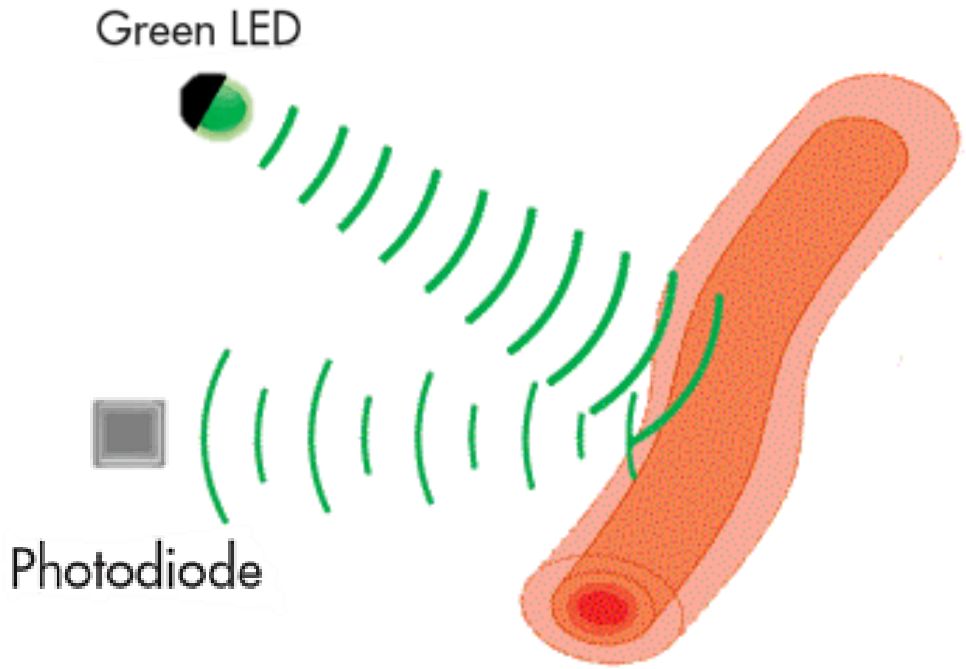
(b) Average heart rate error for naturally walking

- We run two sets of experiments with four rings with and without holes
  - (a) Standing still, (b) Naturally walking
- Figure (a), errors for all cases are less than 10bpm when users stand still.
- Figure (b), errors for all cases are higher than case of (a) when users walk.
  - Especially, case of 'With holes', difference of errors between (a) and (b) are highest because of varying patterns of external light.

What factors do impact quality of measuring heart rate?

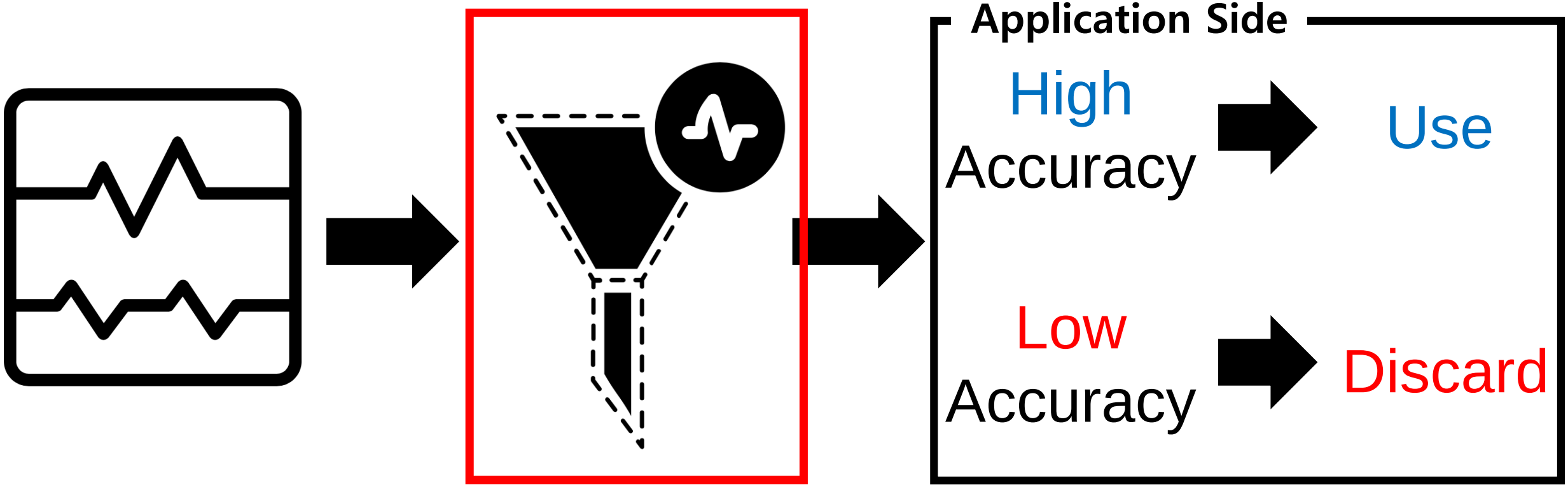


PPG Sensor



- If the PPG Sensor vibrates by motion artifacts, the photodiode cannot read the reflected light from the skin properly
- This causes irregular light intensity readings at the photodiode.

Next steps



- Is a simple threshold-based scheme feasible? **Not really…**
  - Changes between two consecutive readings are too rigorous
  - Users have different watch wearing patterns.

Filter design

1. Set of differences among consecutive PPG light intensity readings:

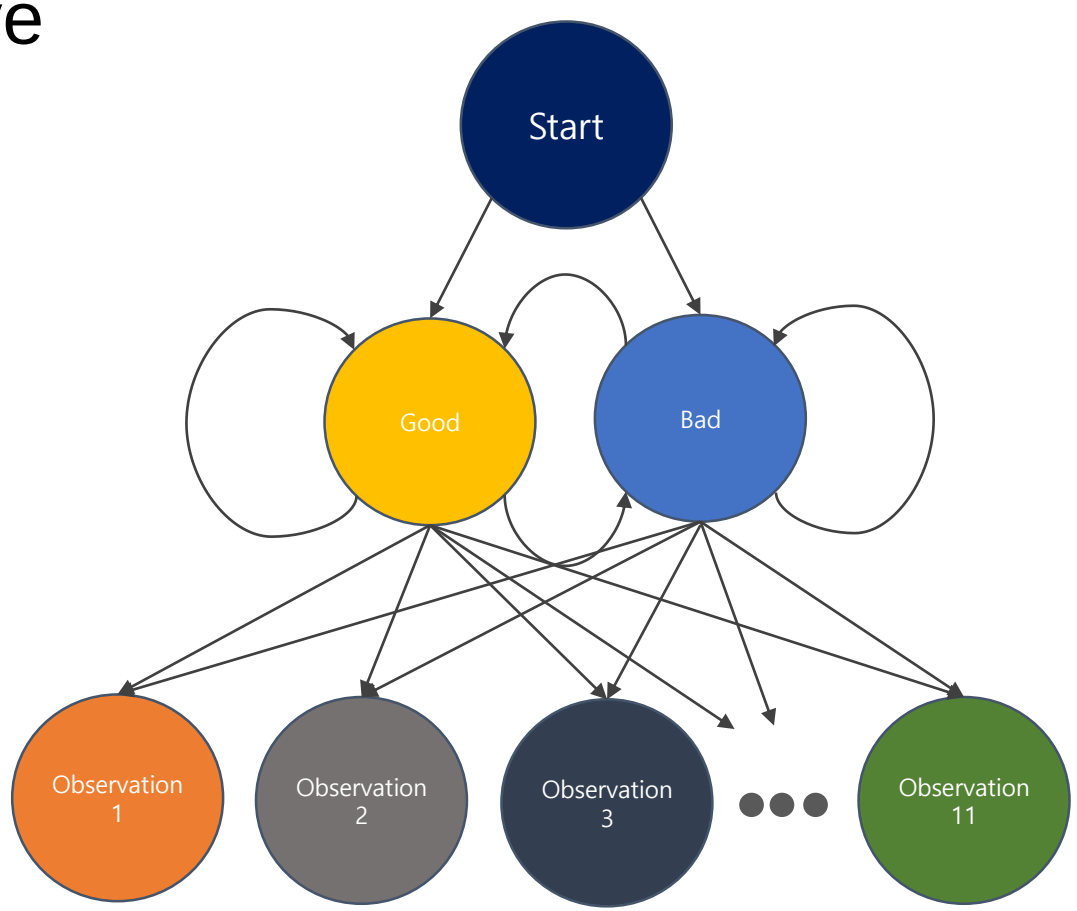
$$\Delta L_{(t:t+w)}$$

2. Identify light intensity step size between observations:

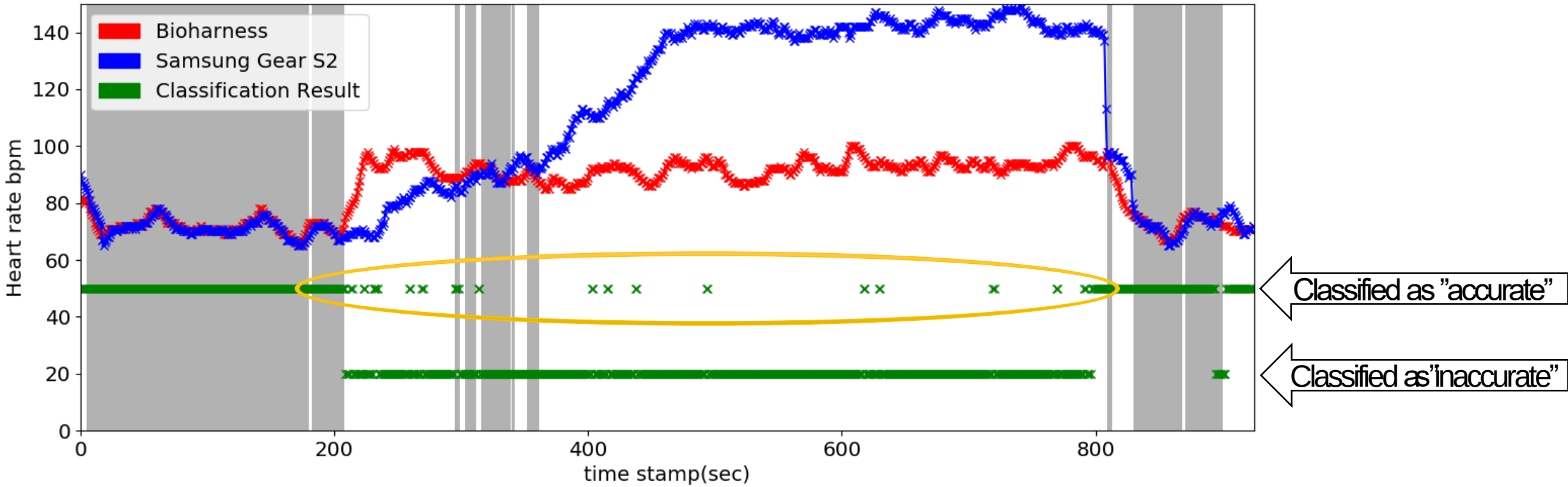
$$S_{step} = \frac{max(|\Delta L_{(t:t+w)}|)}{N_O}$$

3. Compute observation for each time window:

$$O_n = \lfloor \frac{|\Delta L_{(t:t+w)}|}{S_{step}} \rfloor$$



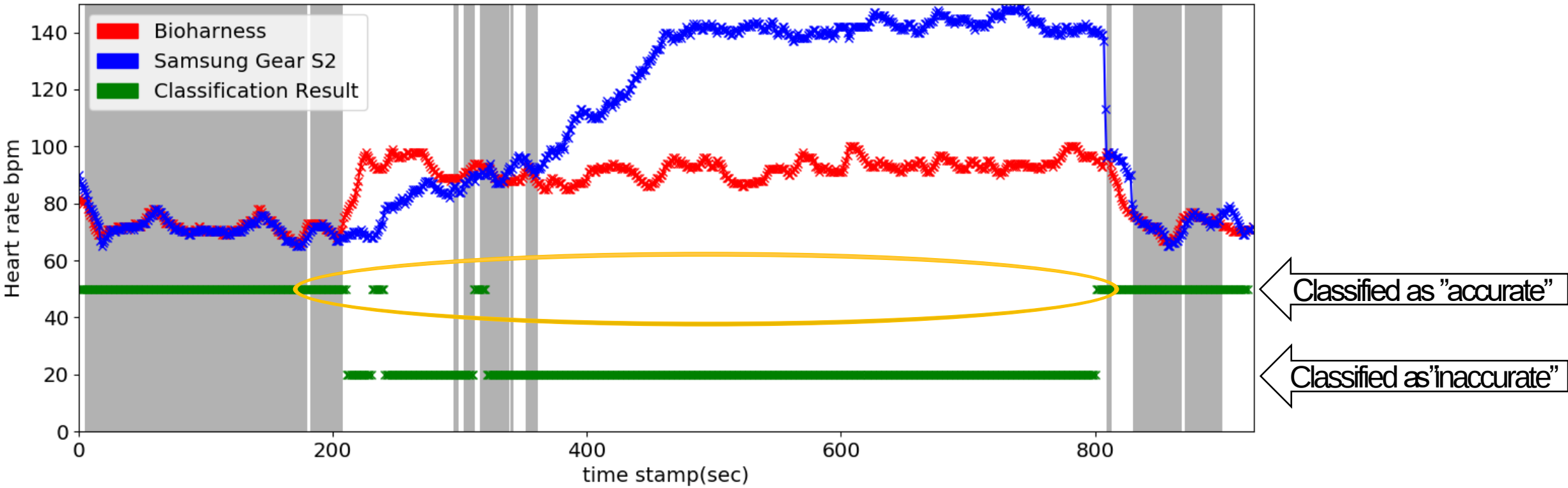
Evaluation : Classification Result



classification results of the proposed filter

- The gray background represents the area in which the ground-truth and the smartwatch readings differ by less than 3 bpm.
- The green dots present our filter’s classification result.

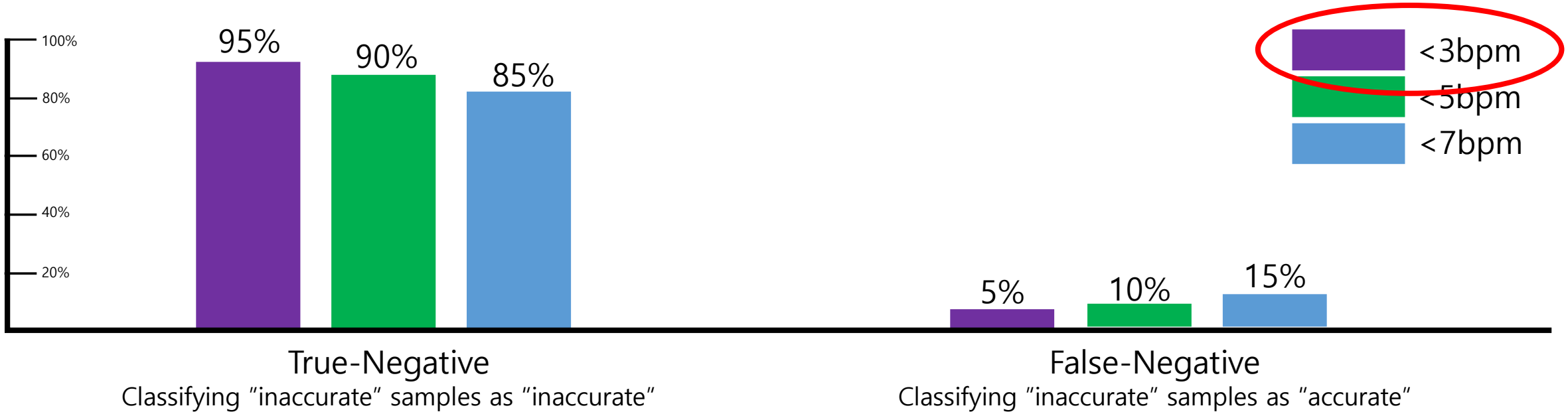
Evaluation : Classification Result



classification results of the filter with moving average

- We focus that the heart rate accuracy does not change instantaneously.
- We use moving average of the values as observation inputs.
  - Conservatively declare "accurate" samples when recent measurements were "inaccurate".

Evaluation

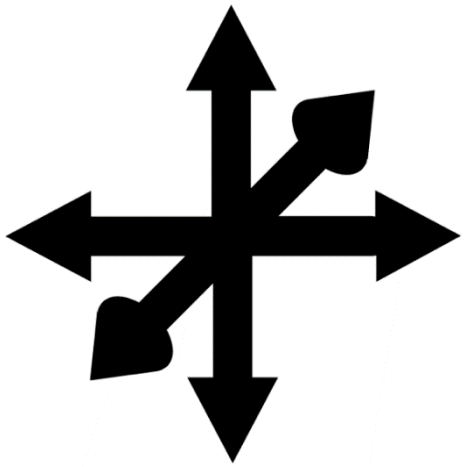


- False-Negative is especially important for clinical devices.
- Our filter shows good performance in identifying inaccurate measurements.

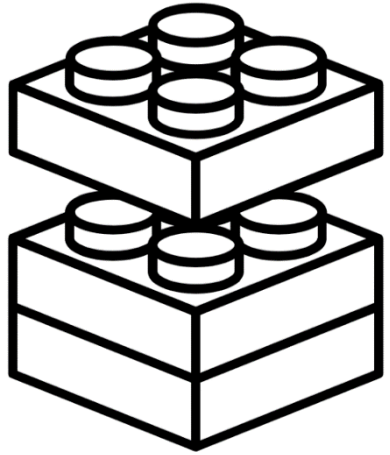
Summary

- Evaluated the heart rate measurement capability of the current smartwatches in various wearing conditions.
- Identify that accelerometer based motion estimations may not be enough to predict inaccurate heart rate readings.
- Design and implement a filter to detect which data samples differ from the ground-truth.

Future works



Combining Accelerometer Information



Modularization for Developers

Highly active exercise

Low Energy Consumption

THANK YOU

Jungmo Ahn

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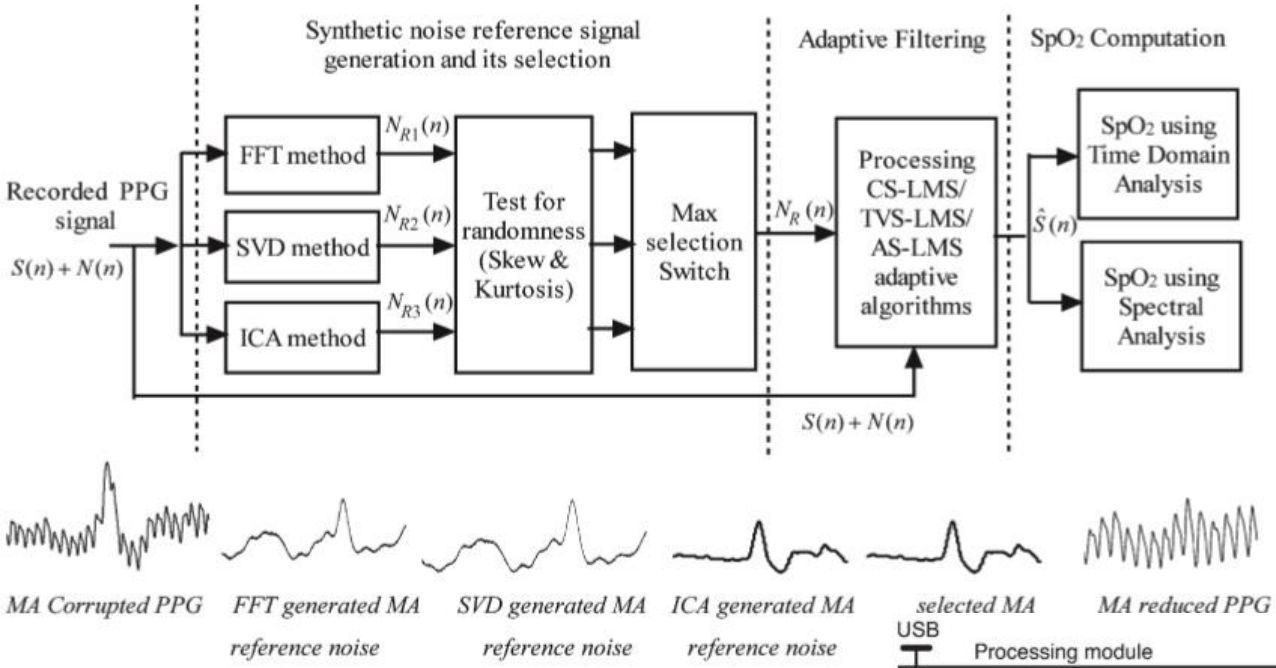
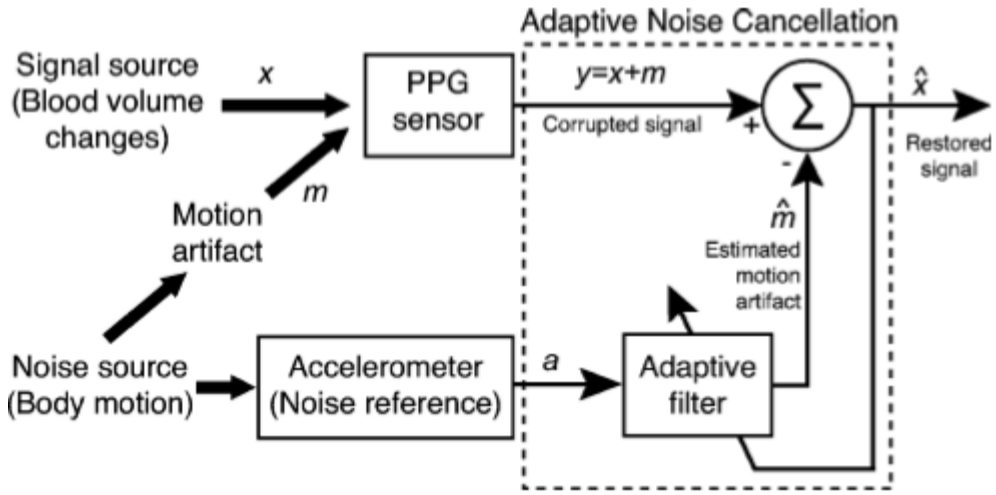
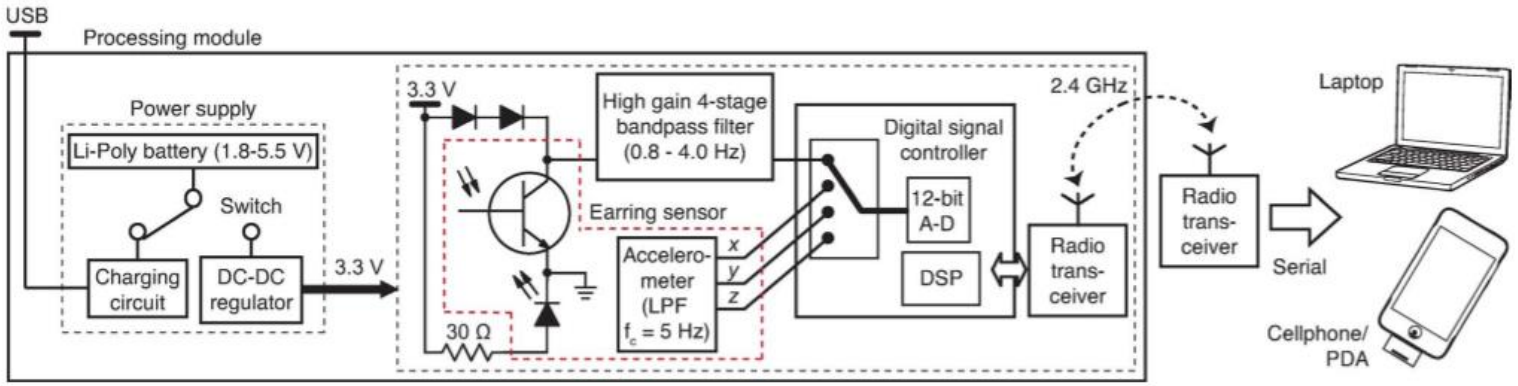
Related Approaches







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M. Z. Poh et al, "Motion-tolerant magnetic earring sensor and wireless earpiece for wearable photoplethysmography," IEEE Trans Inf Technol Biomed (Epub 2010 Feb).