# MusicalHeart: A Hearty Way of Listening to Music

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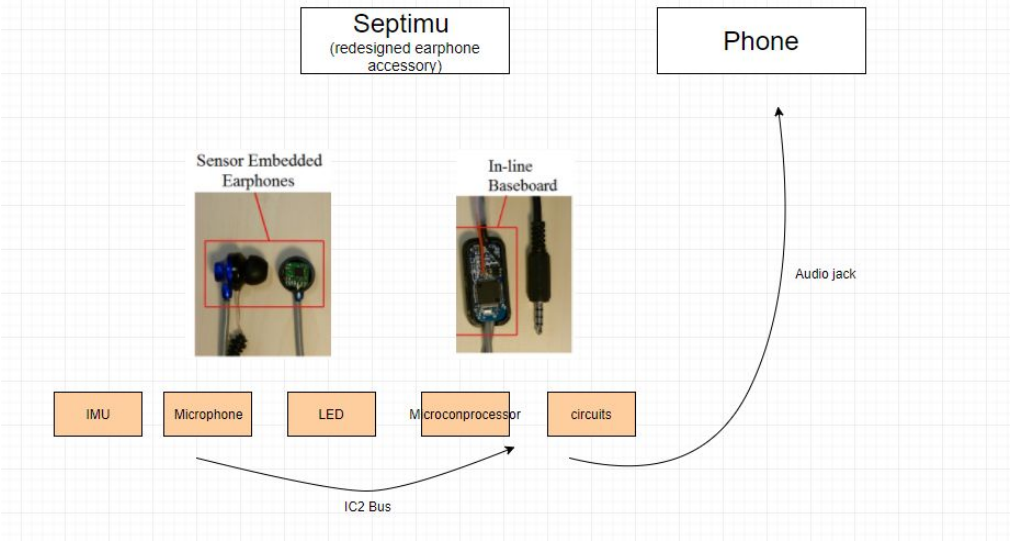
# Problem: Limitations of heart rate monitoring devices

| | | | |
|---|---|---|---|
| 1. | Extra devices | -> | Convenient |
| 2. | Uncomfortable | -> | Non-invasive |
| 3. | Expensive | -> | Low-cost (though not mention the cost) |

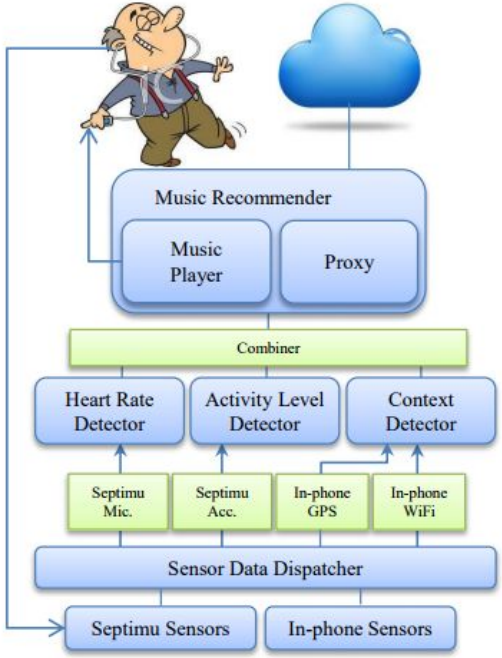
New Feature: Personalization ( desired heart rate -> corresponding music)

[current heart rate, target heart rate, past response, activity level]

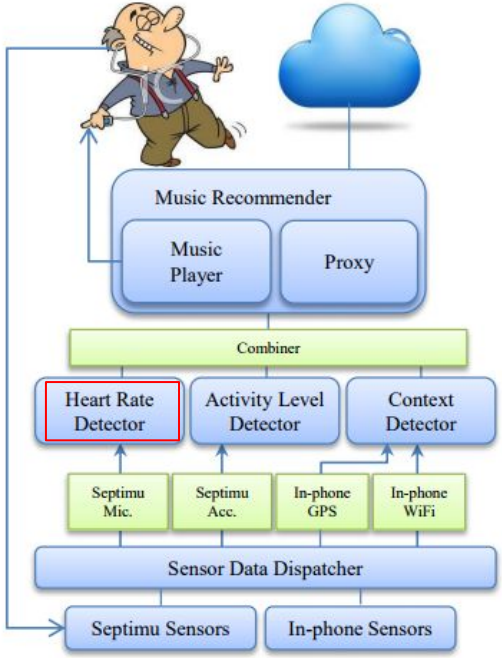
# System Architecture (Septimu)



# System Architecture (MusicalHeart)



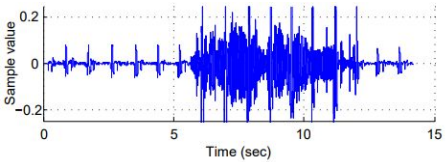
# System Architecture (MusicalHeart)



# Heart Rate Measurement

Microphone in septimu -> sound of heart beats -> filtering ( low pass filter 3.67Hz) -> Detection

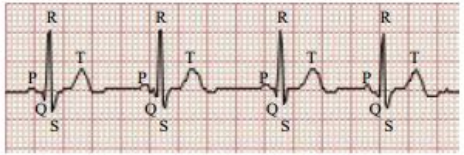
Detection: 1. Selection R waves ( peaks one std larger than mean)




2. Matching 3. Quality Assignment

4. Dynamic Programming a) variance of time differences between two consecutive R waves minimal

b) larger sum of quality



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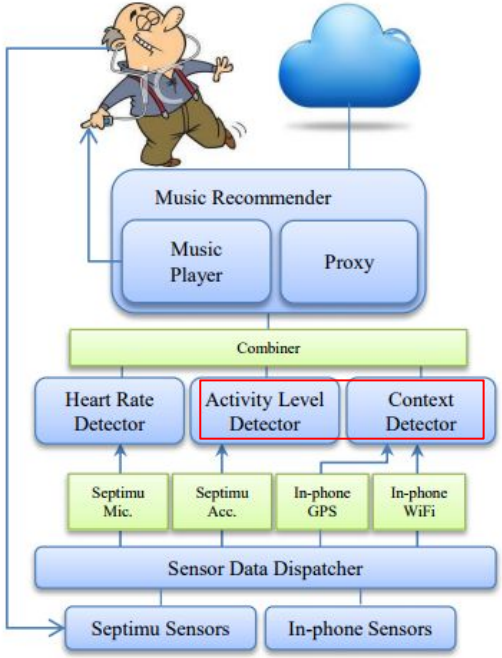


# Activity and Context Detection (Activity)

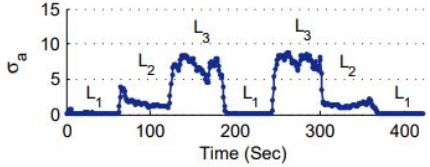
IMU -> activity level

3-axis accelerometer linear magnitude of acceleration

Std ->unsupervised k-means clustering learning -> 3 levels

$$|a_{ear}| = \sqrt{a_x^2 + a_y^2 + a_z^2}.$$

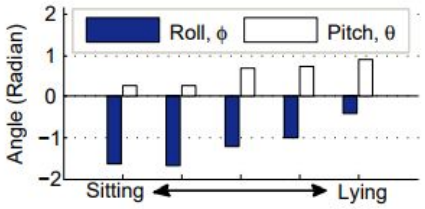
calculate std from average



# Activity and Context Detection (Context)

3-axis accelerometer -> detecting sitting/lying

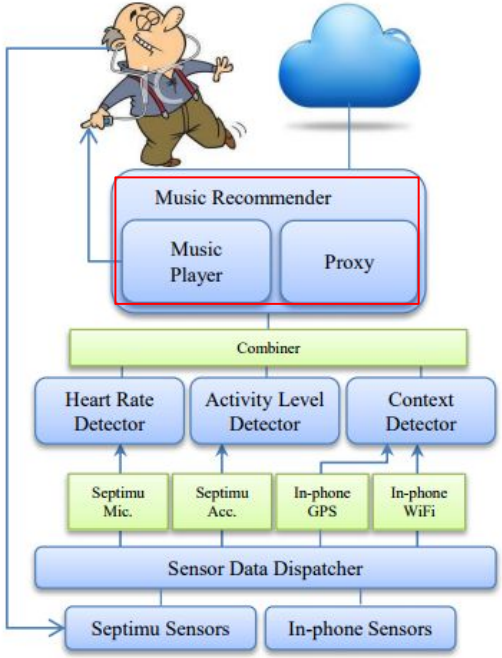
From experiments: threshold of -1.5 for roll/ 0.5 for pitch




Phone sensors (location service)-> Indoor/Outdoor

| Context | Activity Lev | In-Out | Velocity | Roll, Pitch |
|---|---|---|---|---|
| LIE | L1 | Indoor | - | $> -1.5, > 0.5$ |
| SEATED | L1 | In/Out | - | $< -1.5, < 0.5$ |
| TRAVEL | L1 | Out | $> 25\ mph$ | - |
| SLOWMOVE | L2 | In/Out | $< 3\ mph$ | - |
| BIKE | L2 | Out | $< 15\ mph$ | - |
| GYM | L3 | In | - | - |
| JOG | L3 | Out | - | - |

# System Architecture (MusicalHeart)



# Music Suggestion and Rating (Music Suggestion)

PI-controller (slower change to heart rate, take the past errors in count)

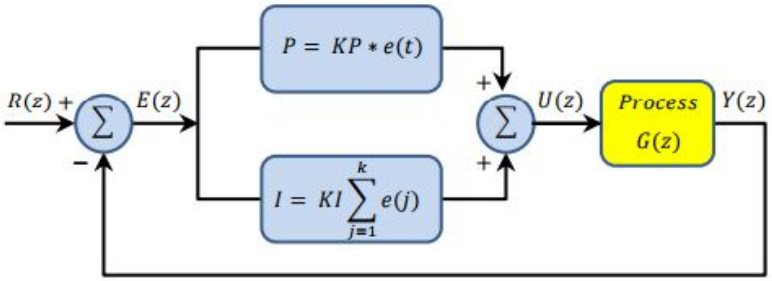
G(z): human

U(z): suggested change in feature of music

Y(z): current heart rate

R(z): desired heart rate

E(z): difference between Y(z) and R(z)



# Music Suggestion and Rating(Music Suggestion)

Change of music ->(first order) change of heart rate (A, B parameters person specific )

$$G(z) = \frac{A}{z - B}$$

Design goals:

| Goal | Requirement |
|---|---|
| Stability | Poles of $F_R$ are inside unit circle. |
| Accuracy | Steady-state-error < 5 BPM |
| Settling Time | $k_s \leq 1$ |
| Overshoot | $M_P < 0.1$ |

$$K_P = \frac{B - 0.00034}{A}, \text{ and } K_I = \frac{0.9755}{A}$$

# Music Suggestion and Rating(Rating)

Each song ( 0 - 5 ) <5: BPM error <5, >0: BPM error >20

Steady state BPM error each song makes at different activity level and desired heart rate

$$\hat{r}(s_u) = \alpha \sum r(s_i) p(s_i, s_u) + (1 - \alpha) \bar{r}(s_u)$$

{Si} set of rated songs {ri} corresponding ratings

Su: song not listened; p: similarity between two songs; α: coefficient of how much reply on other users' feedback, lower means more depend on others' feedback

# Technology and Algorithm Evaluation

37 people. Measure **heart rate**, different activity levels, with/without music

{lying, sitting idle} - 17

{walking indoors and outdoors} - 10

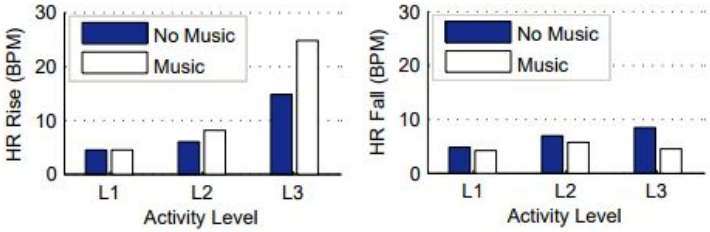
{jogging} - 10

Ground truth: ECG device(relaxed),  pulse oximeter(moving)

# Technology and Algorithm Evaluation

Q: Whether the music have any relation to the activity levels?

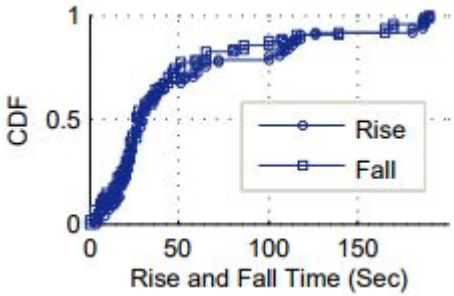
A: The higher the activity level, the more effective



# Technology and Algorithm Evaluation

Q: How much is the effect of music in rising or dropping one's heart rate?

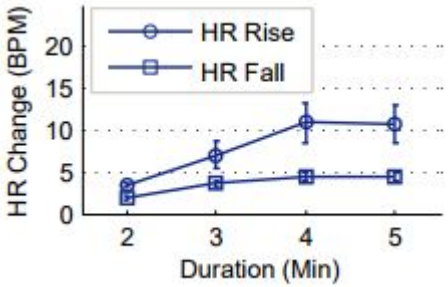
A: Not instantaneous, most apparent between 25 -50 s



# Technology and Algorithm Evaluation

Q: How long the music takes to make the effect?

A: The longer a person listens, the more is its effect. (???)



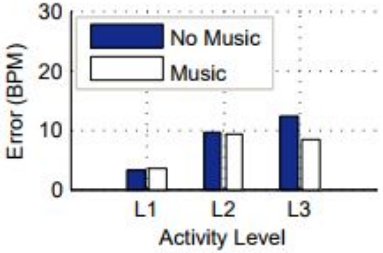
# Evaluation of Heart Rate Measurement

Musical heart BPM errors

Similar with/without music -> filter works

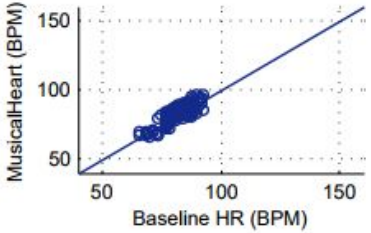
Higher level of activities -> higher error rate

Loose contact of earphone after long period of jogging  -> poor reception of audio signal

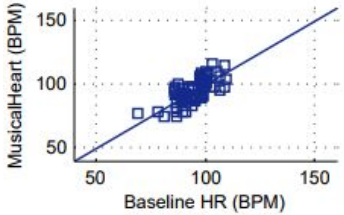


# Evaluation of Heart Rate Measurement

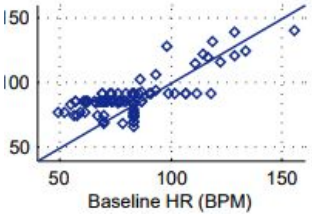
Correlation between MusicalHeart BPM and baseline HR BPM




0.85(good)




0.84(good)




0.75(not that good)

Horizontal points correspond to the looseness of the earphone

Vertical points corresponds to the inability of the pulse oximeter to report the pulse during high movements

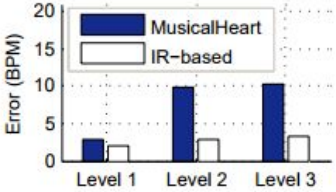
# Evaluation of Heart Rate Measurement

Comparison of heart rate measurement with an IR-based method

MusicalHeart: 7.5 BPM mean error in all levels

IR: 2.69 BPM mean error in all levels

Future work



# Evaluation of Activity Level Detection

3 activities, corresponding to 3 activity levels, train classifier with 60% of the collected data, validation on the remaining 40%

The sequence of activities, {L1,L2,L3,L1,L3,L2,L1}

| Actual \ Predicted | $L_1$ | $L_2$ | $L_3$ |
|---|---|---|---|
| $L_1$ | 0.9998 | 0.0002 | 0 |
| $L_2$ | 0 | 0.9997 | 0.0003 |
| $L_3$ | 0 | 0.0280 | 0.9720 |

**Table 6. Single activity.**

| Actual \ Predicted | $L_1$ | $L_2$ | $L_3$ |
|---|---|---|---|
| $L_1$ | 0.989 | 0.011 | 0 |
| $L_2$ | 0 | 0.951 | 0.049 |
| $L_3$ | 0 | 0.037 | 0.963 |

**Table 7. Activity sequence.**

Accuracy: 99.1% 96.8%

# Real Deployment

demonstrate that MusicalHeart measures heart rate, detects activity levels, and suggests appropriate songs while a person is exercising

2 male, 2 female

| Time | Intensity | Pace |
|---|---|---|
| 5 min | 60%-70% | Walk at a comfortable pace to warm up. |
| 3 min | 70%-80% | Increase speed a few increments until working harder than the warm up pace. This is the baseline. |
| 2 min | 80%-90% | Increase speed again until working slightly harder. |
| 3 min | 70%-80% | Decrease speed back to baseline. |
| 2 min | 80%-90% | Increase speed once again until working slightly harder than baseline. |
| 5 min | 60%-70% | Decrease speed back to a comfortable level. |

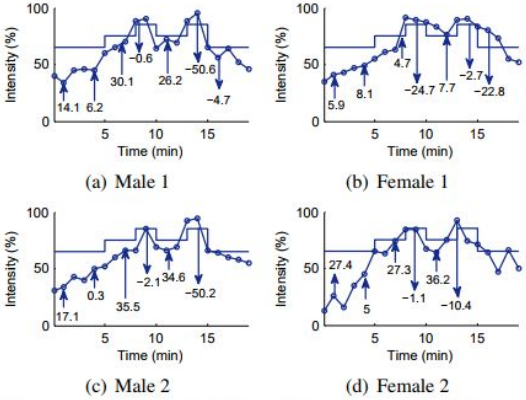



**Figure 17. The desired intensity, achieved intensity and activation of control signals are shown.**

# Real Deployment

Curve line: Standard deviation of accelerometer data

Stairs: detected activity levels L2 and L3

a)male 1, 7-8 min glitch, slow down

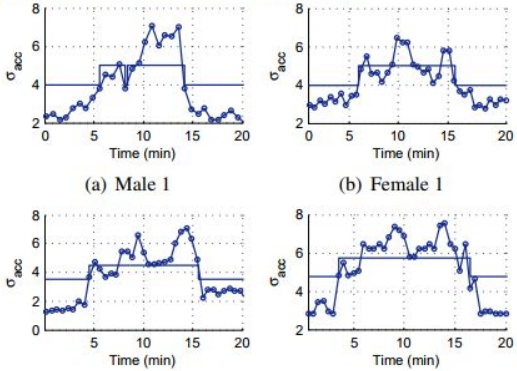



**Figure 18. Standard deviation of accelerometer data and boundary between activity levels $L_2$ and $L_3$ are shown.**

# Overview

Septimu and MusicalHeart

75%-85% accuracy of detecting heart rate with average of 7.5 BPM

96.8% accuracy of activity level

Help users in achieving a desired exercising intensity with an average error of less than 12.2%