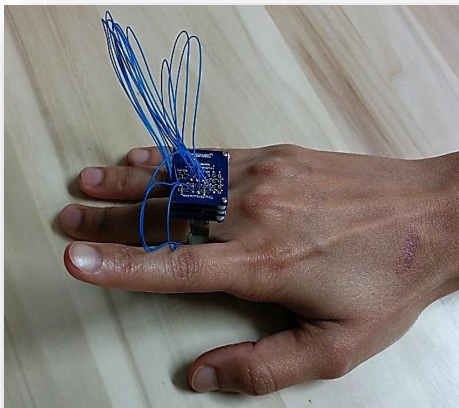
Wearables –
for Fingers and Ears

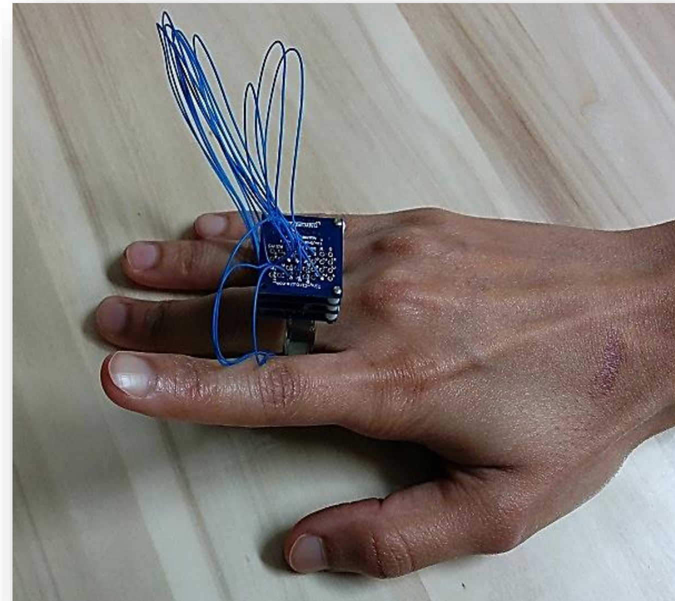
Shahriar Nirjon
UNC Chapel Hill

Two Wearables



- **Ring**
  Finger gesture detection
  (TypingRing, MobiSys '15)

- **Earbuds**
  Pulse and motion detection
  (Musical-Heart, SenSys '12)



Typing Ring

A Wearable Ring Platform for Text Input

Shahriar Nirjon, Jeremy Gummeson, Dan Gelb, and Kyu-Han Kim

Hewlett-Packard Labs

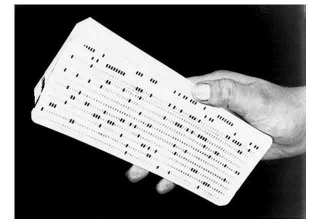
MobiSys 2015

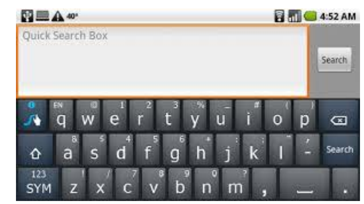
Text Input Methods

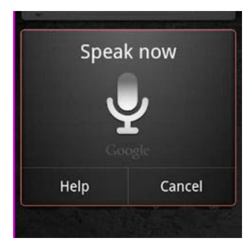
As computing systems evolve, so do their input methods

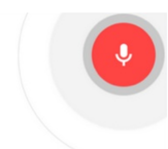
Computing Devices

Input Devices









Ring – portable, mobile, always with us

Existing ring based input devices

Usage of a Ring as a Gesture Interface, NFC tag, Mouse, and for Notifications

Fin – Numeric pad and gesture interface

NFC Ring – Two NFC tags to read/write

ThumbTrack – acts as a mouse

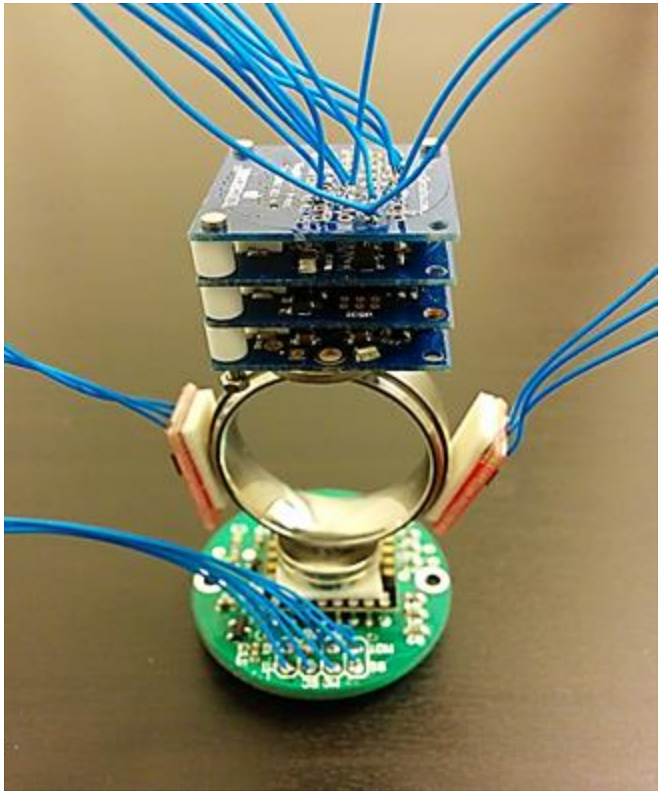
SmartyRing – alert, notification, and remote control

Typing Ring

Introducing the Typing Ring

Typing Ring

- A wearable, portable, accessory that allows us to input text into computers of different forms.



Specification

- Connects wirelessly as a standard Bluetooth Smart keyboard.
- Works on surfaces such as – a table , a wall, or even your lap.
- Over 98% accurate in detecting typed keys.
- Yields a typing speed of up to 50 keys/min.
- Yields up to 15,500 keys with full charge.
- Weighs ~ 15 gm

Working Principle of Typing Ring

How to type with the Typing Ring

Wearing It

The ring is worn in the middle finger.

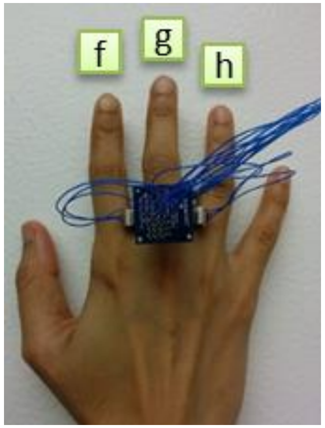
Seeking 3-Letter Zones

As the user hovers his hand on a surface, 3-consecutive keys on a on-screen keyboard is highlighted.

Typing a Key

The User makes a typing gesture with one of three fingers and the corresponding key is typed in.

On-screen visual feedback



Typing with 3-fingers

Special Use Cases

Special scenarios beside the generic one

Tiny-Screen Devices

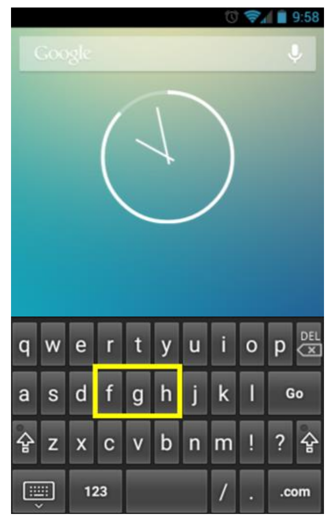
Devices where we cannot use touch keyboards

Saving Screen Space

Typing Ring saves screen space with minimized soft-keyboards.

Typing On-the-Go

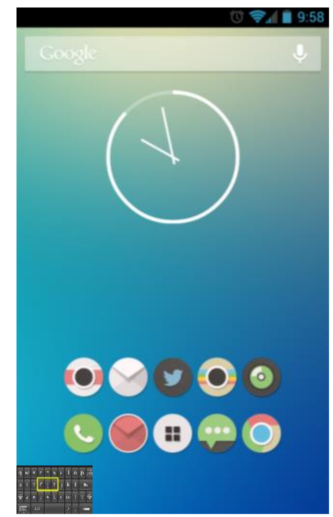
Wear a keyboard everywhere.



Full-scale

Soft KB

Vs.



Just Enough

Visual Feedback

Hardware Architecture

Hardware components of the Typing Ring

Microcontroller

Sensing; Determining and Sending the Key.

Accelerometer Sensor

Movement of middle finger; Always On.

Proximity Sensor

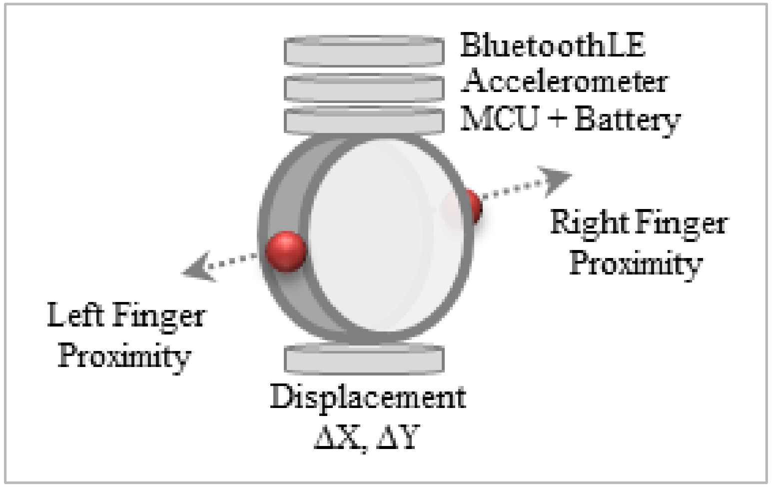
Determining the typing finger.

X-Y Displacement Sensor

Seeking the zone; Optical mouse sensor;

Bluetooth LE

Sending the key event.



Firmware Architecture

Software inside of the Typing Ring

Sensing Layer

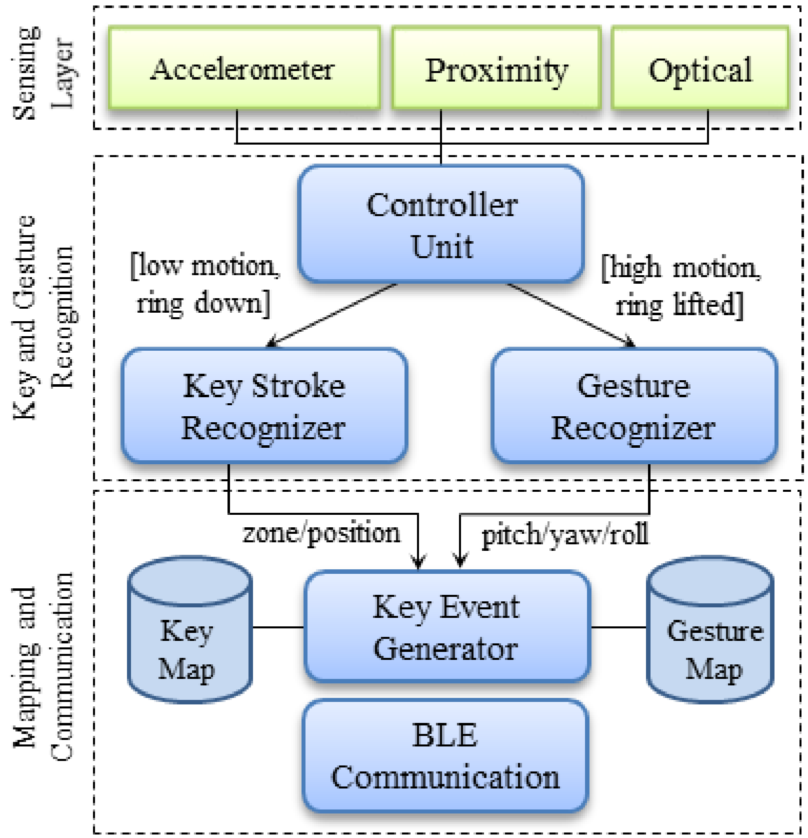
- Read and store 3 types of sensor readings in a bounded circular queue

Finger/Gesture Recognizer

- Algorithms to determine 3-letter zone, typing finger, and 3D gesture

Mapping and Communication

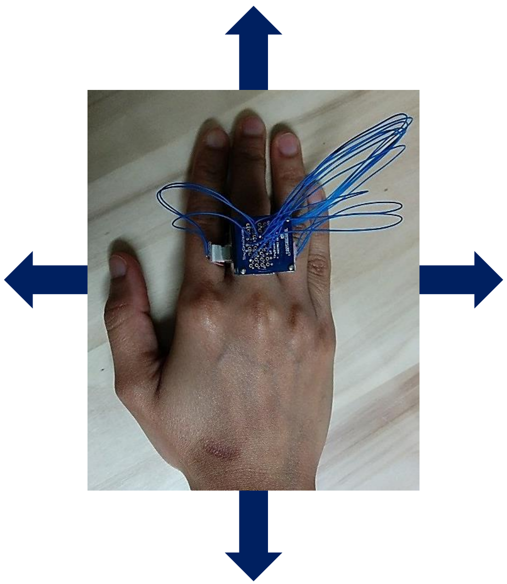
- Standard key events for a typed key
- Fake key event (ALT+NUM) for zone
- Maps gestures to shortcut keys and sends the key event

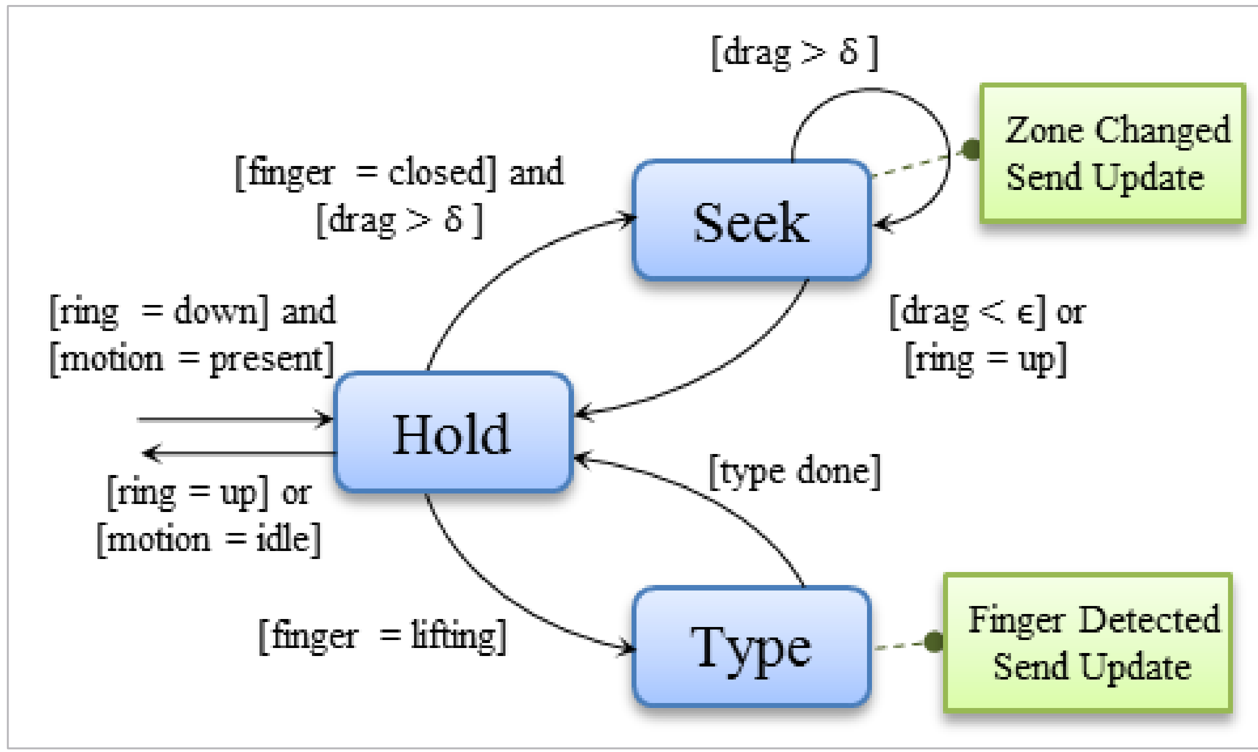


Key Stroke Detection

Zone seeking and making a typing gesture

State Machine to Stage Zone Seeking and Typing

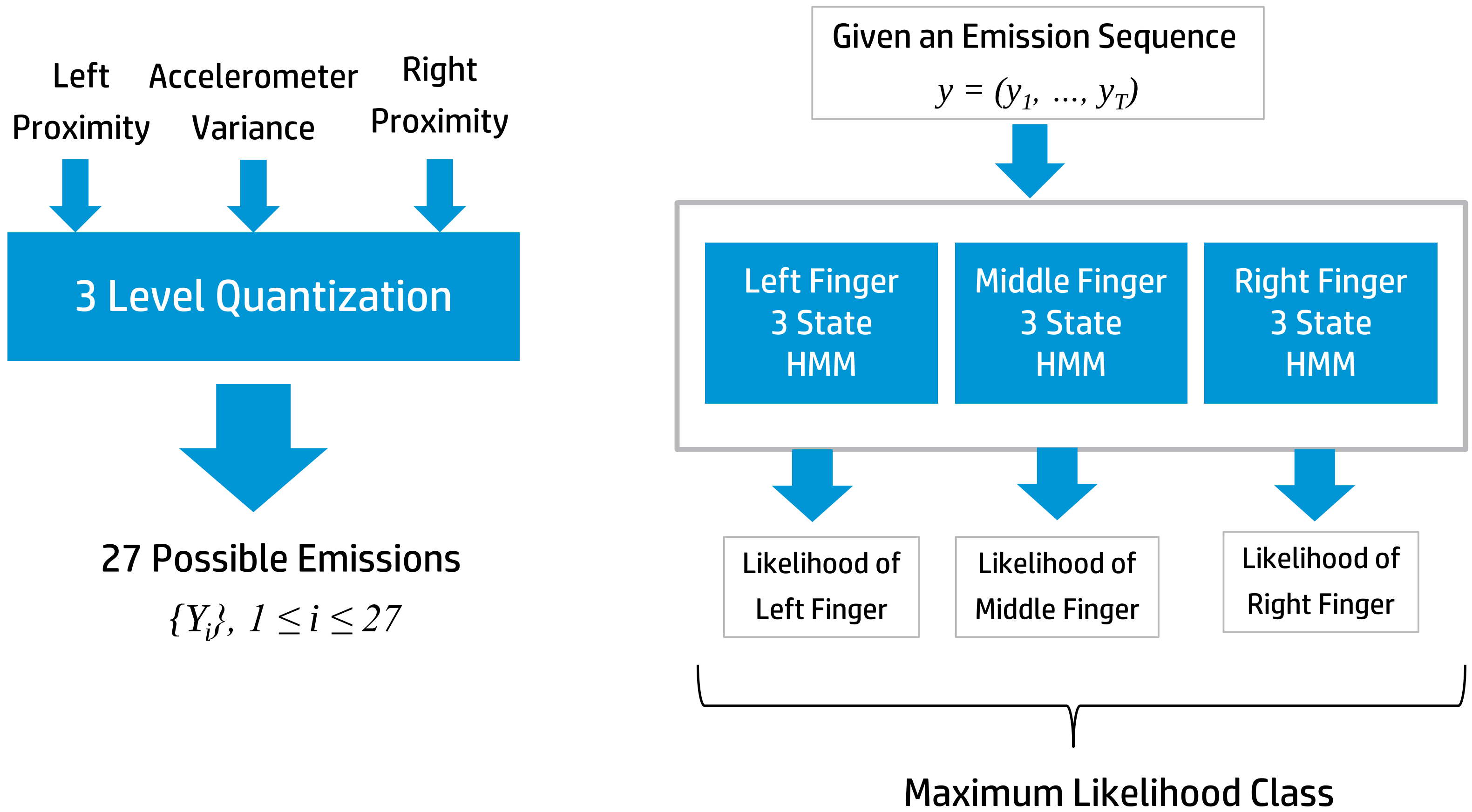




Typing Finger Detection

Detecting the typing finger among the three with a HMM

Block Diagram of Algorithm Execution

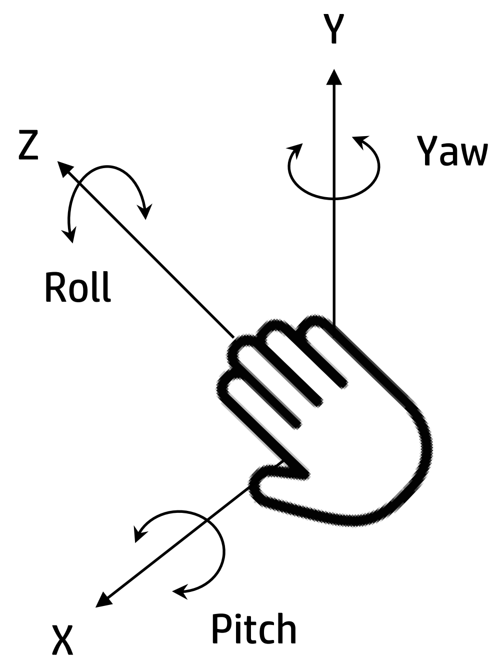


Gesture Shortcuts

Simple 3D gestures mapped to short-cut keys

Gesture to Key Mapping

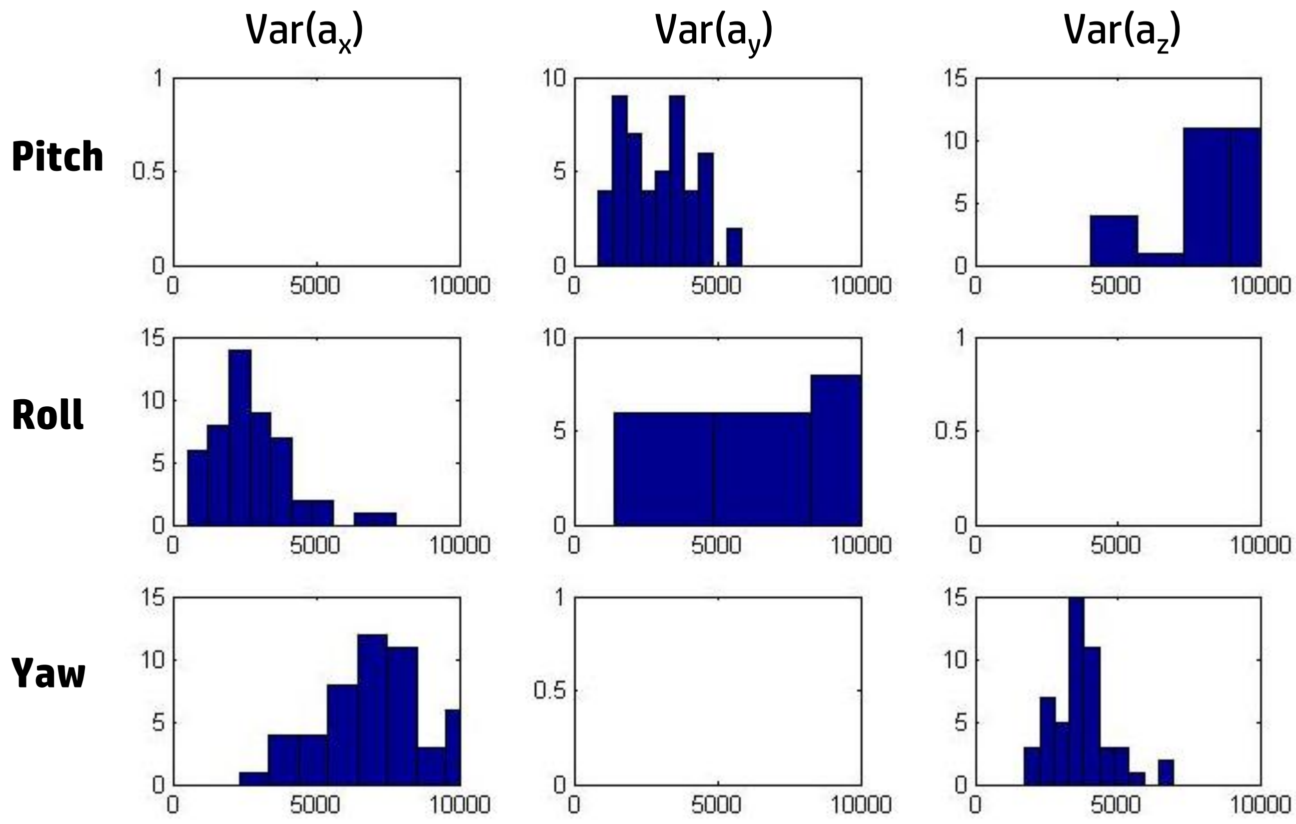
Gesture	Times Repeated	Key
Pitch	1	Space Bar
	2	Enter
Roll	1	Shift
	2	Caps Lock
Yaw	1	Delete (letter)
	2	Delete (word)



Gesture Shortcuts

3D roll, pitch and yaw detection

Variance of 3-axis Accelerometer Readings

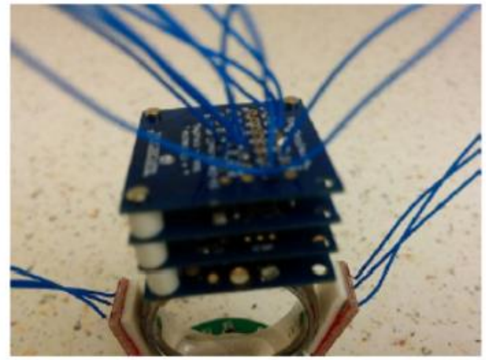


Prototype Implementation

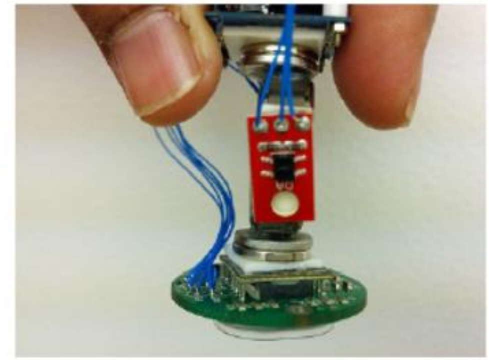
Hardware, communication, and visual feedback

Hardware

- TinyDuino boards (20 mm x 20 mm)
  - MCU – Atmel ATmega328P MCU (8MHz, 32KB Flash, 2KB RAM, 1KB EEPROM)
  - Accelerometer – Bosch BMA250 3-axis accelerometer shield.
  - BLE – Bluegiga BLE112 module
- Proximity – QRE 1113 IR line sensor (3 mm sensitivity)
- Displacement - ADNS 9800 optical motion sensor (high precision)
- Total wt. 15.5 gm
- Could be miniaturized by 2x-3x



(a) Top View



(b) Side View

(c) Bottom View

Prototype Implementation

Hardware, communication, and visual feedback

Communication

- Bluegiga BLE112 Bluetooth LE SoC
- BGLib API
- HID over GATT profile
- Two types of HID reports for reporting zone changes and key values.

Visual Feedback

- Android Custom Keyboard
- Two types of visual feedbacks – regular full-scale and 3-key only (for tiny screen devices)

Full-scale visual feedback

Only 3-key visual feedback
(for tiny-screen devices)

Prototype Evaluation

Evaluating the Typing Ring prototype with micro and macro benchmarks

System Measurements

Measuring the executing time and energy consumption

Empirical Evaluations

Collecting raw sensor data for analysis and parameter tuning of algorithms

User Study

Evaluating the performance (e.g. speed) of Typing Ring

Execution Time

Computation and communication delay

Methodology – Precise Time Measurement

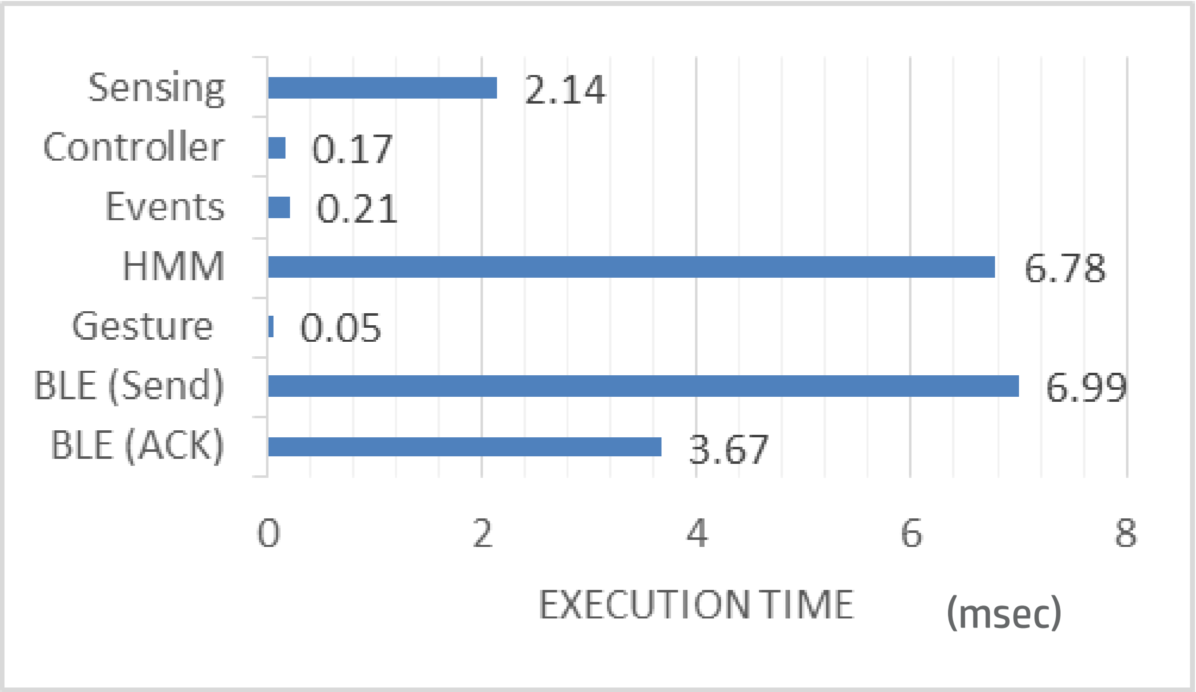
```
digitalWrite (pin, HIGH);
// Ring firmware code
// segment to time
digitalWrite (pin, LOW);
```

Saleae Logic16

Execution Time

Computation and communication delay

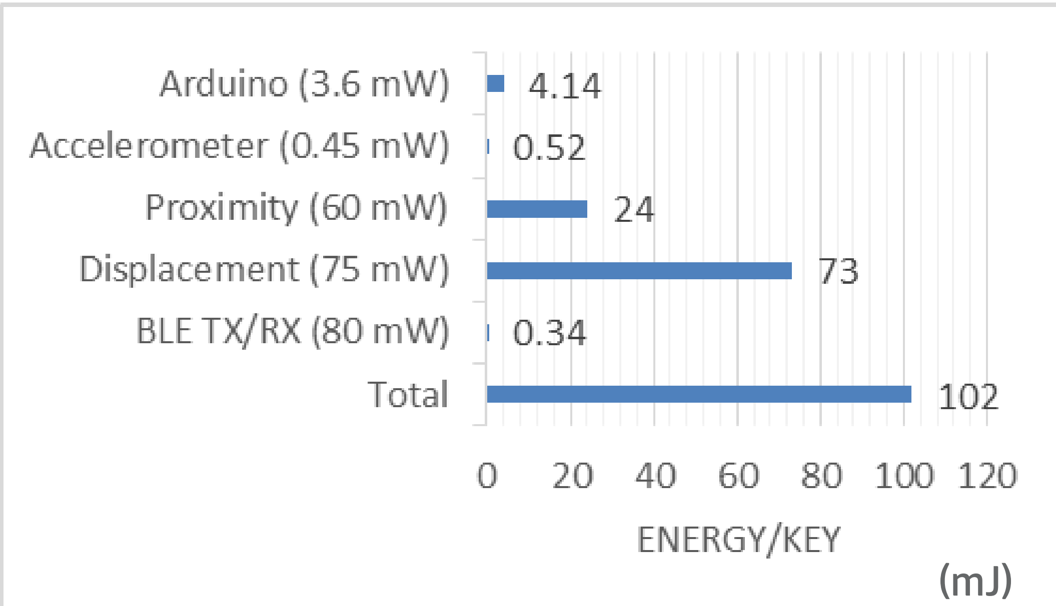
Results – Execution Times of Major Computation and Communication Components



Energy Consumption

Energy profile and estimated lifetime

Results – Energy Consumption of Various Components



125 mAh

13,500 – 15,500 Keys

3.8 – 4.3 Hours

Empirical Evaluation

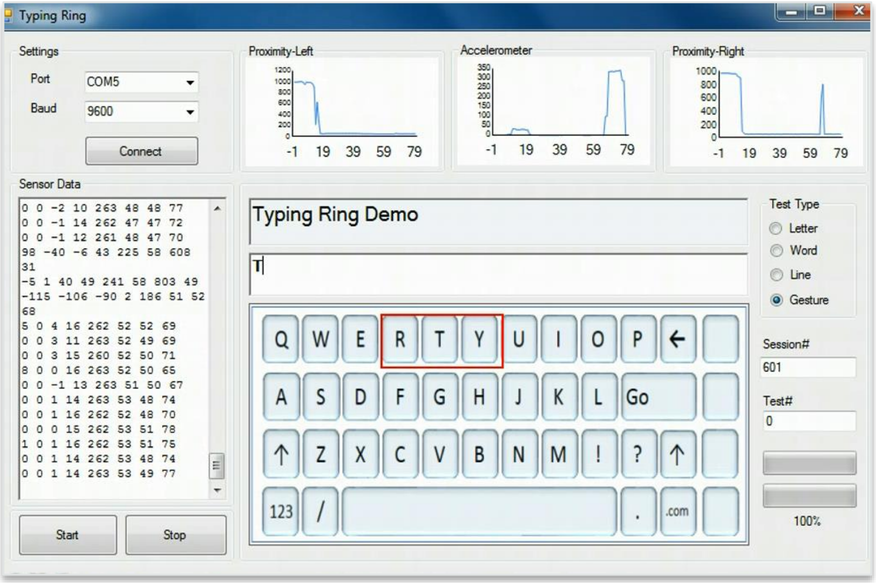
Data collection for offline analysis and parameter tuning

Goal

- Collecting raw sensor readings
- Use data for training the classifier

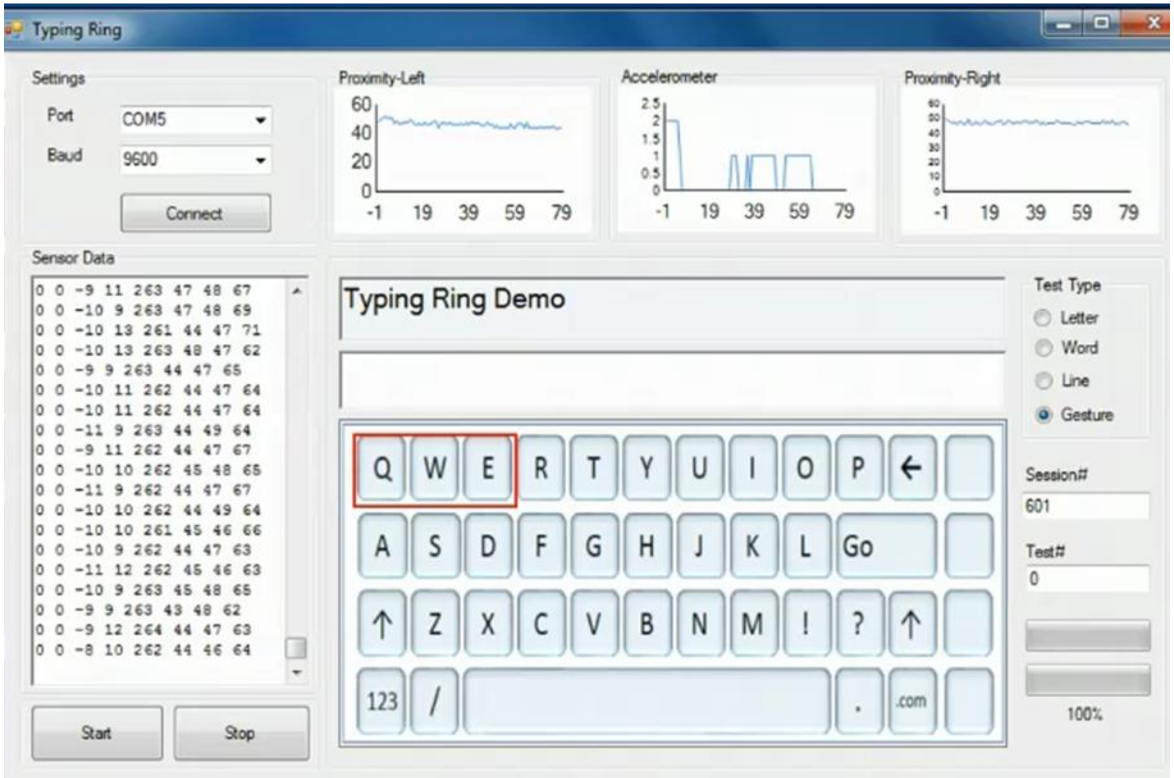
Data Collection Settings

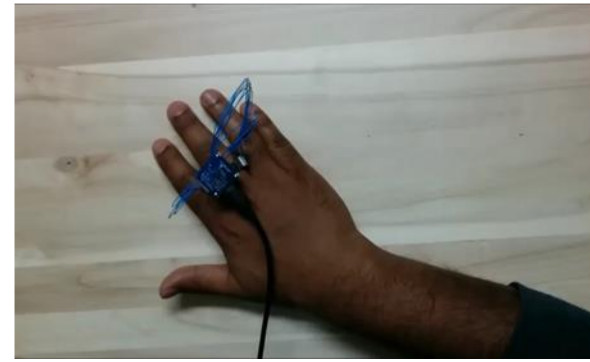
- 18 Participants
- Each types 50 random characters, 5-15 phrases, and makes 30 gestures.
- Full on-screen keyboard for visual feedback
- Bootstrap classifier (for data collection)
- Sensor sampling at 100 ms interval



Data Collection Program
(Running on a laptop connected to the ring over USB)

Video Demo


Typing Ring
Settings
Port
COM5
Baud
9600
Connect
Proximity-Left
Accelerometer
Proximity-Right
Sensor Data
0 0 -9 11 263 47 48 67
0 0 -10 9 263 47 48 69
0 0 -10 13 261 44 47 71
0 0 -10 13 263 48 47 62
0 0 -9 9 263 44 47 65
0 0 -10 11 262 44 47 64
0 0 -10 11 262 44 47 64
0 0 -11 9 263 44 49 64
0 0 -9 11 262 44 47 67
0 0 -10 10 262 45 48 65
0 0 -11 9 262 44 47 67
0 0 -10 10 262 44 49 64
0 0 -10 10 261 45 46 66
0 0 -10 9 262 44 47 63
0 0 -11 12 262 45 46 63
0 0 -10 9 263 45 48 65
0 0 -9 9 263 43 48 62
0 0 -9 12 264 44 47 63
0 0 -8 10 262 44 46 64
Start
Stop
Typing Ring Demo
Q W E R T Y U I O P
A S D F G H J K L Go
Z X C V B N M ! ?
123 / . .com
Test Type
Letter
Word
Line
Gesture
Session#
601
Test#
0
100%



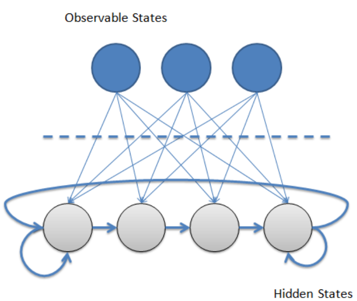
Typing Finger Detector's Accuracy

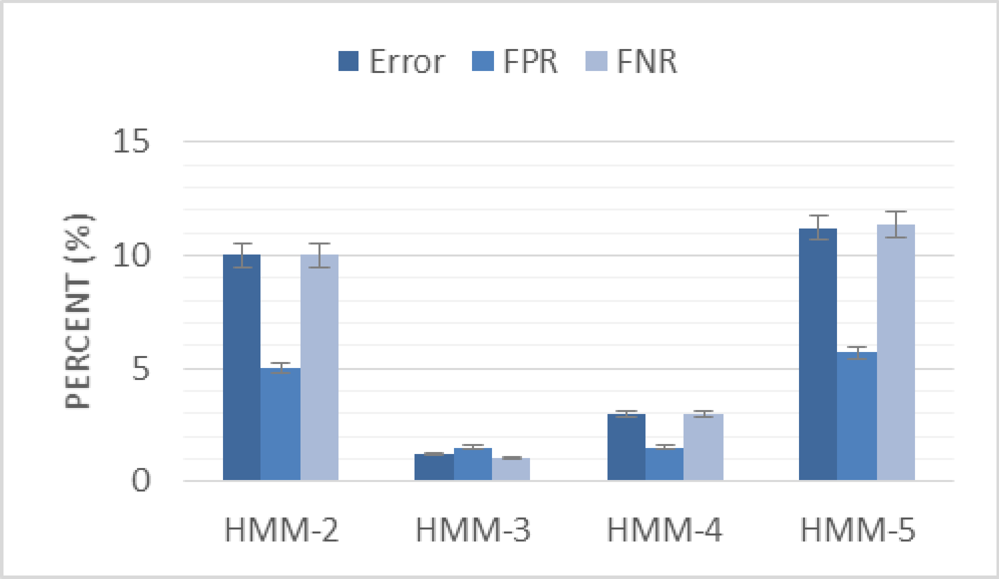
Different models of HMM

Comparing HMMs with 2, 3, 4 and 5 states

HMM

- Empirical Dataset
- 1000 training iterations
- Randomized initialization
- Repeated 10 times
- 70% training, 30% test

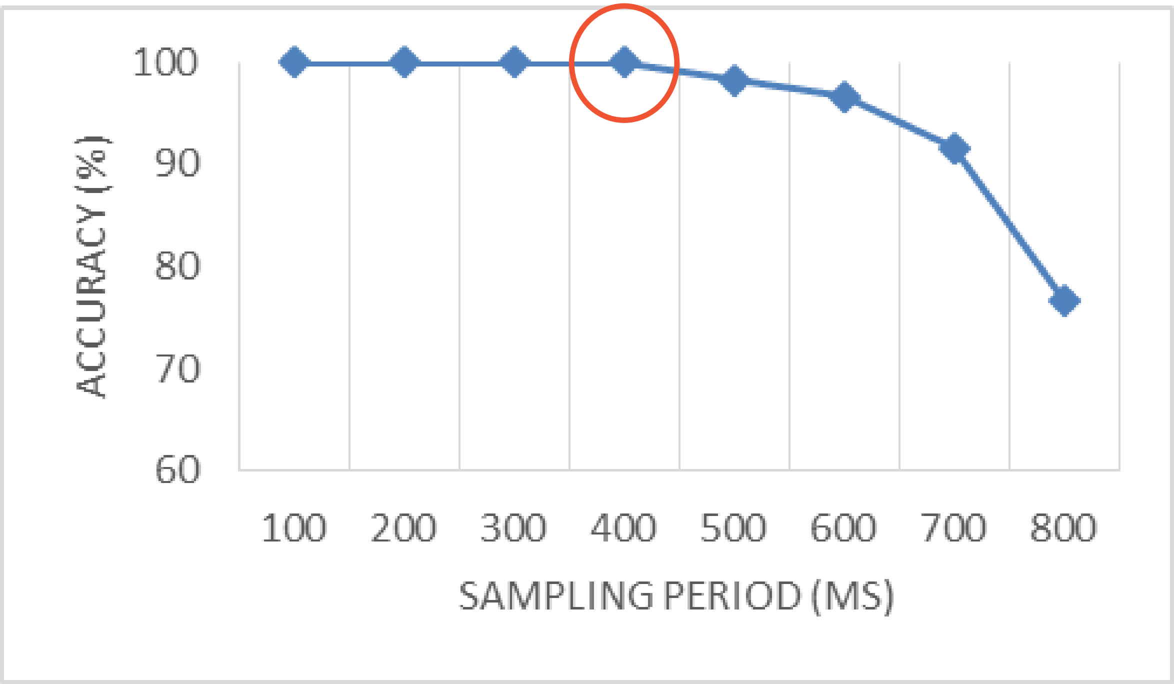




Gesture Shortcut Detector's Accuracy

Detecting roll, pitch, and yaw

Result – Sampling rate vs. Accuracy



User Study

Typing speed and experience

Participants

- 7 participants
- 2 sessions each (10-15 min sessions)

Text and Typing Settings

- Concatenated phrases from MacKenzie set
- Manual corrections and gestures allowed
- Full on-screen keyboard for visual feedback
- No auto-corrections

Two Baselines

- Android on-screen soft keyboard.
- Win7 mouse click-based on-screen keyboard.

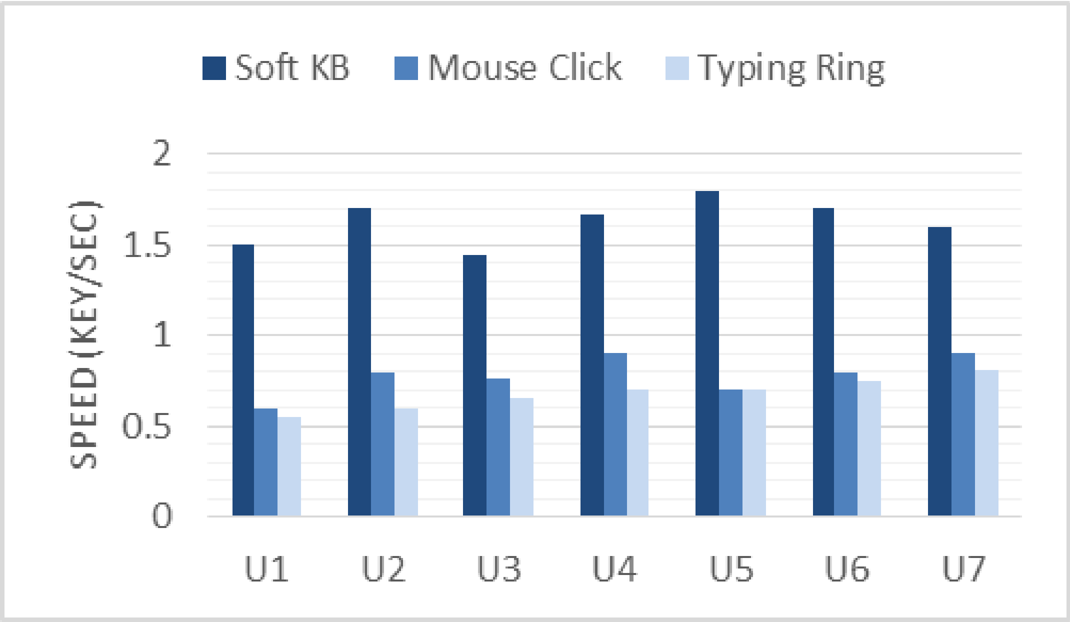
Baseline 1 – Soft KB

Baseline 2 –mouse clicks on KB

Typing Speed - Comparison

Rate of valid key entries

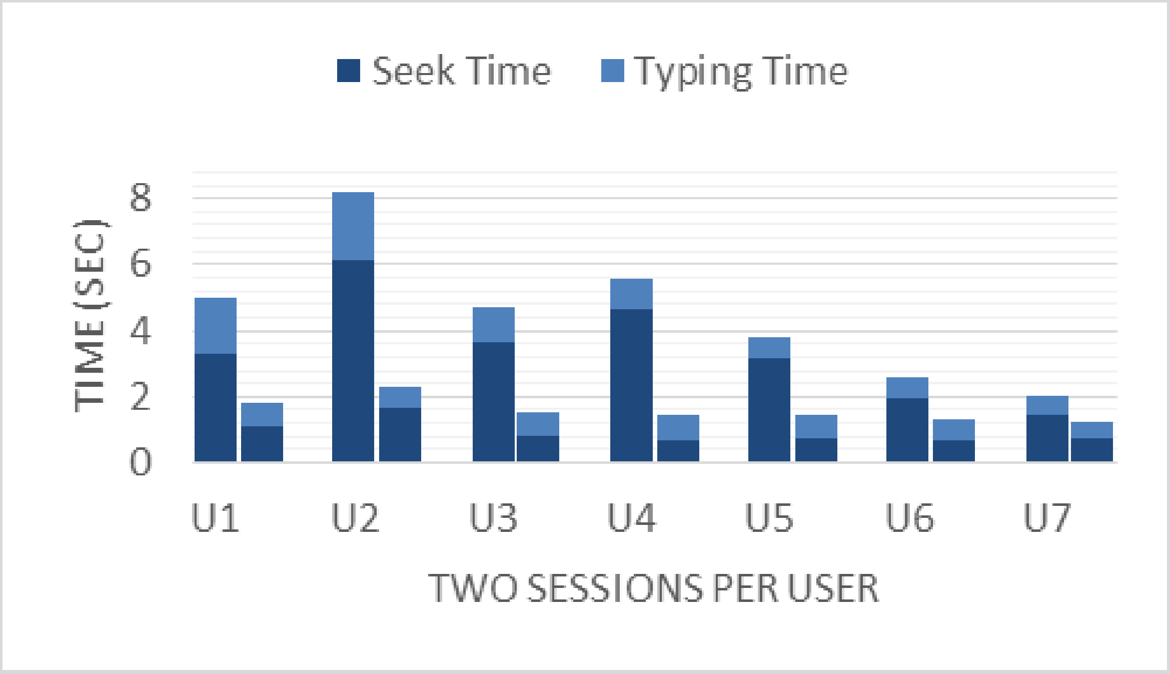
Result – Typing speed on a Soft KB, with Mouse Clicks, and Typing Ring



Typing Speed – Learning Effect

Learning effect – it gets better with time

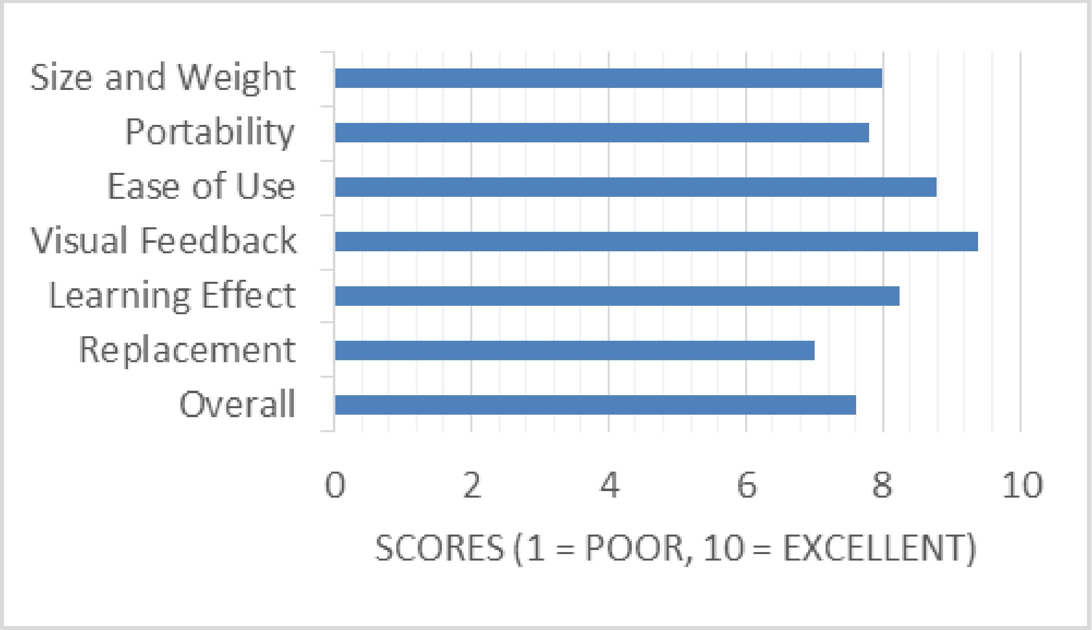
Result – Session 1 vs. Session 1 with Typing Ring



User Survey

Understanding user experience

Result – Survey on various usability aspects of Typing Ring



Musical Heart

A Hearty Way of Listening to Music

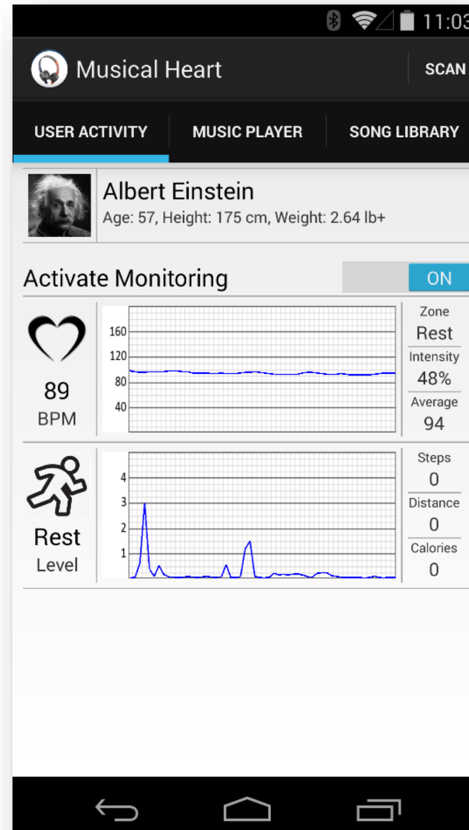
Shahriar Nirjon, Dezhi Hong, John Stankovic, + 7 more
University of Virginia and Microsoft Research

SenSys 2012

The Musical Heart System

A biofeedback-based, context-aware, and automatic music recommendation system for smartphones.

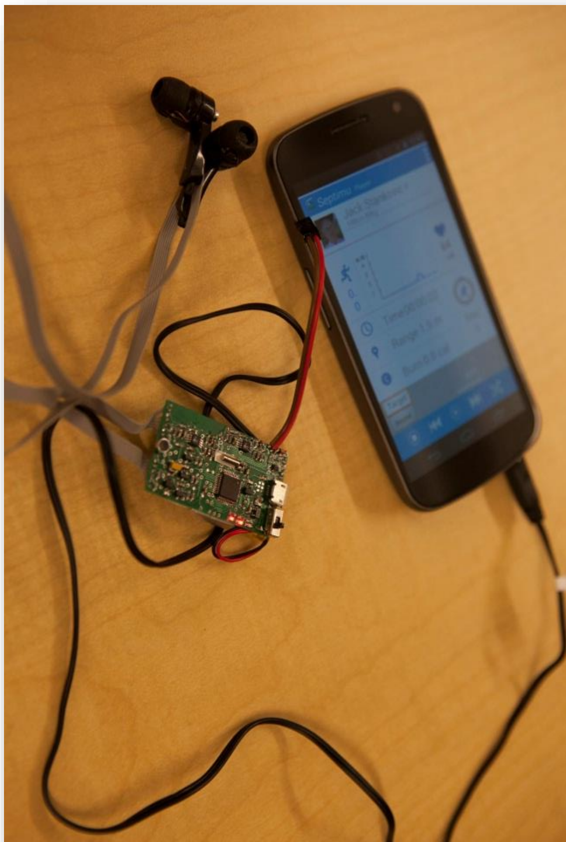
Sensor Equipped Earphones (Septimu)



Android App

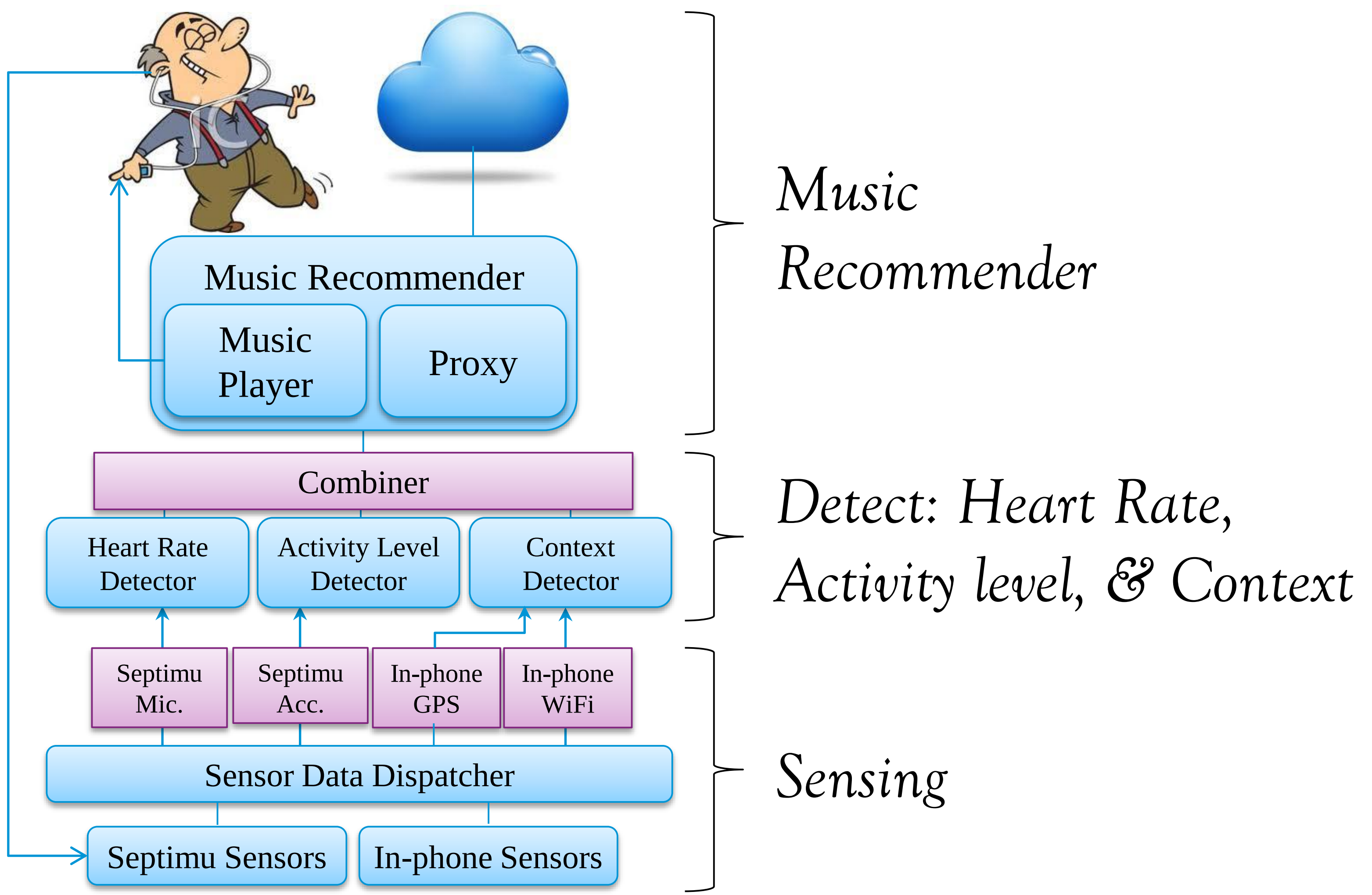
Musical Heart: Wearable Sensors

Complete System



- **Sensors:**
  - *IMU*
  - *Microphone*
  - *IR Reflective Sensor*
  - *Thermometer*
- **Communication:**
  - *Audio Jack*
  - *Bluetooth*
- **Power:**
  - *Li-Polymer battery*

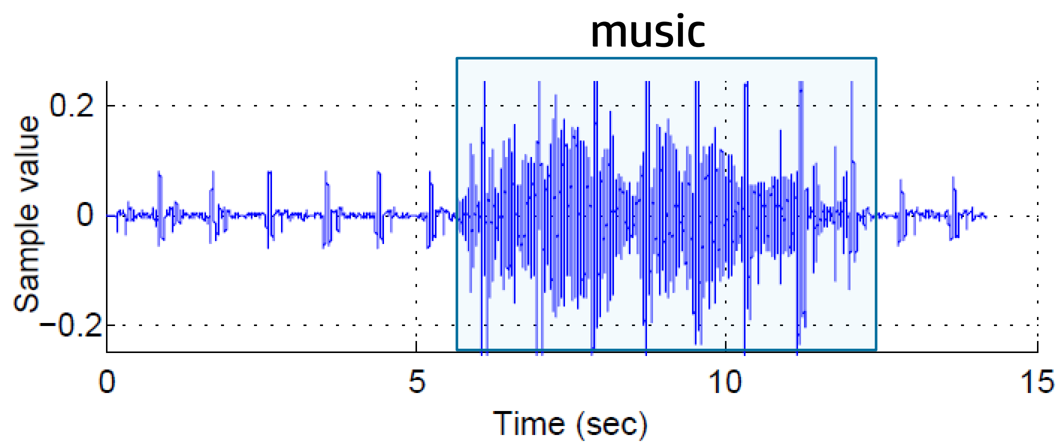
Musical Heart: Smartphone App



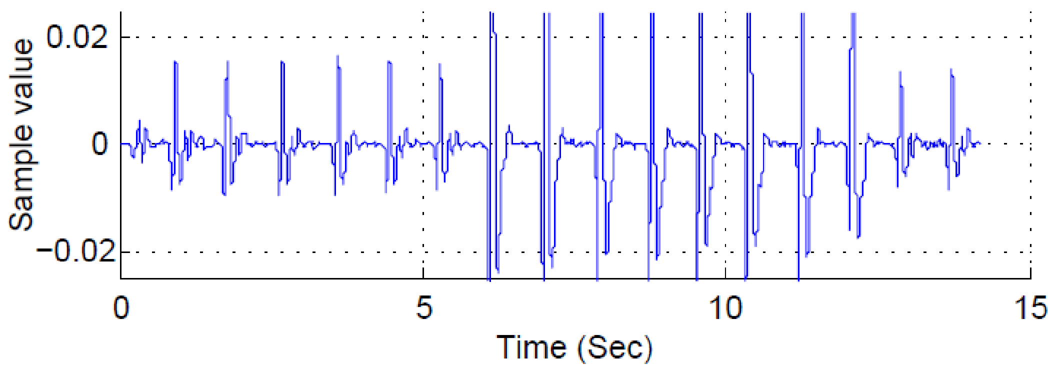
Algorithm – Heartrate Detection

Filtering: A low pass filter to remove non-heart beat signals.

Signals from Ear
(music + heart beats)



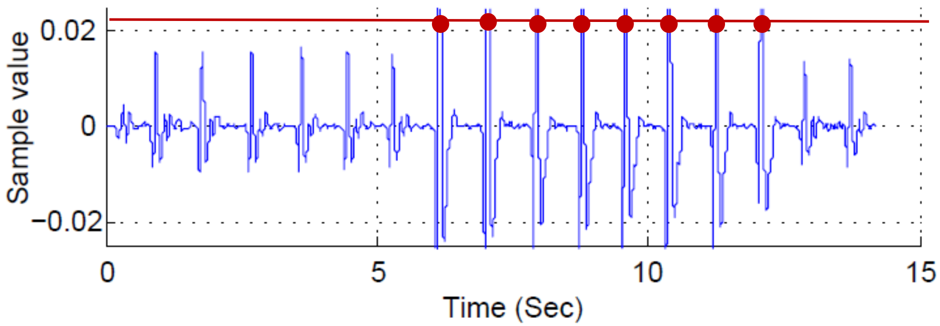
After filtering
(heart beats)



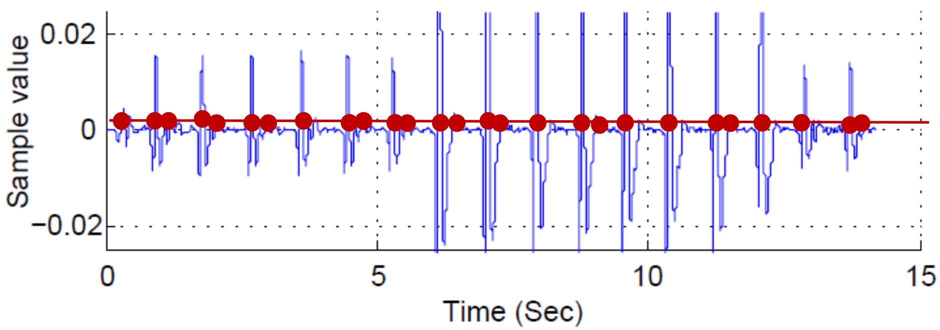
Algorithm – Heartrate Detection

Detection: simple thresholding does not work

Large Threshold:
too few candidates (8)



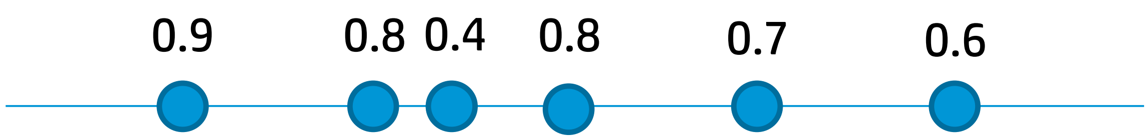
Small Threshold:
too many candidates (27)



Algorithm – Heartrate Detection

Detection: as an optimization problem

Step 1 – Use a small threshold to pick initial candidates and score each based on their peak-peak distance and resemblance to a heart beat.

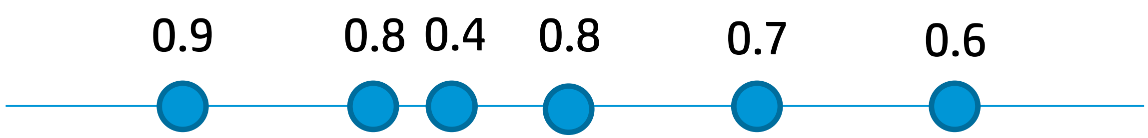


6 Candidate for Heartbeats

Algorithm – Heartrate Detection

Detection: as an optimization problem

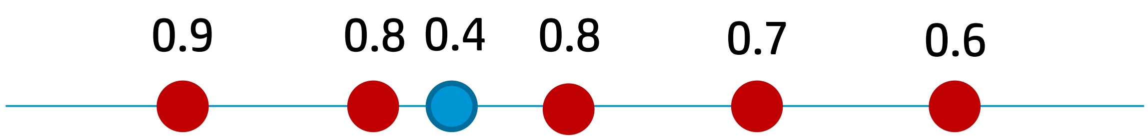
Step 2 – Maximize the sum of scores, while minimize the variance of time-gaps. *(for an assumed number of beats)*



Algorithm – Heartrate Detection

Detection: as an optimization problem

Step 2 – Maximize the sum of scores, while minimize the variance of time-gaps. (for an assumed number of beats)



For example, to select 5 out of the 6 candidates:

Max Sum = 3.8

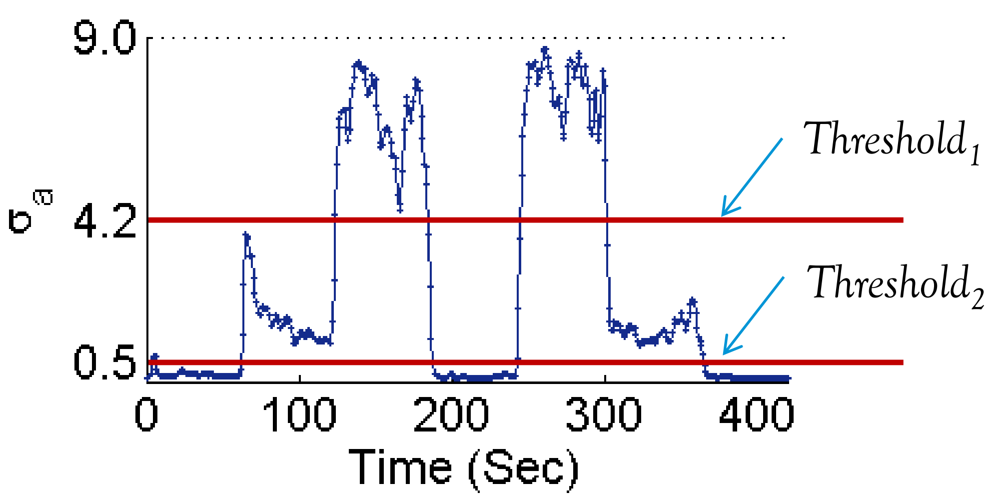
Min Variance = 0, if we select the red ones.

Repeat Step 3 for HR = [40, 220]

Algorithm – Activity Level Inference

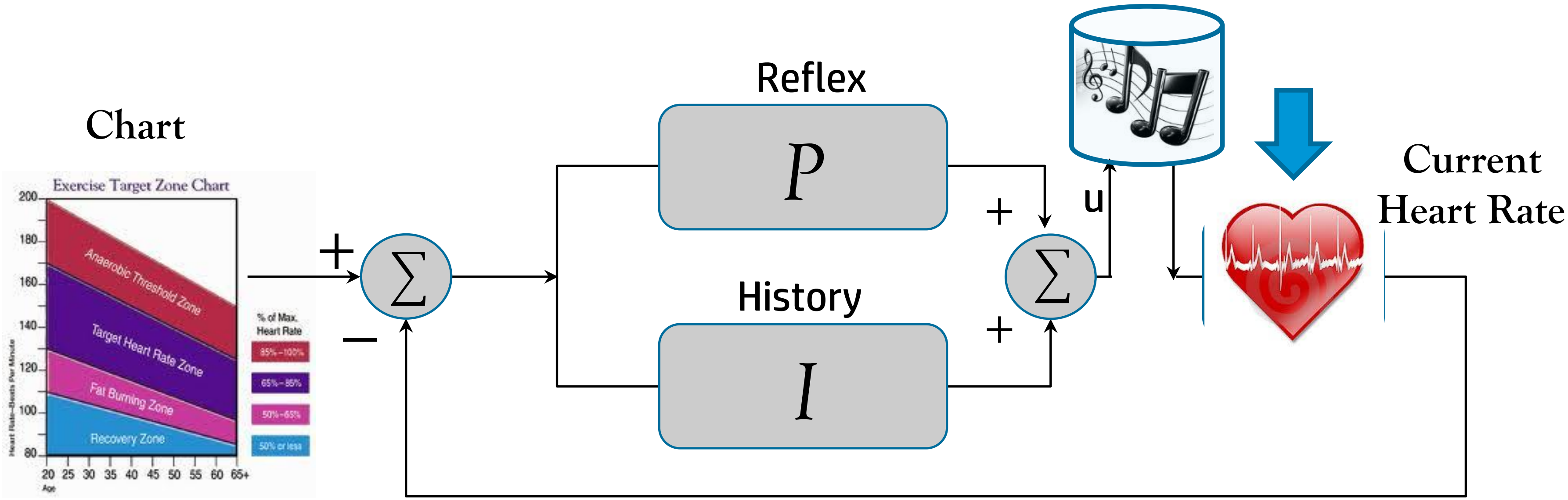
Activity Levels: Low (L_1), Medium (L_2), High (L_3)

Example: $L_1 \rightarrow L_2 \rightarrow L_3 \rightarrow L_1 \rightarrow L_3 \rightarrow L_2 \rightarrow L_1$

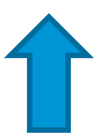


We use k-means clustering to learn the thresholds

Algorithm – Biofeedback and Music Player



Desired
Heart Rate

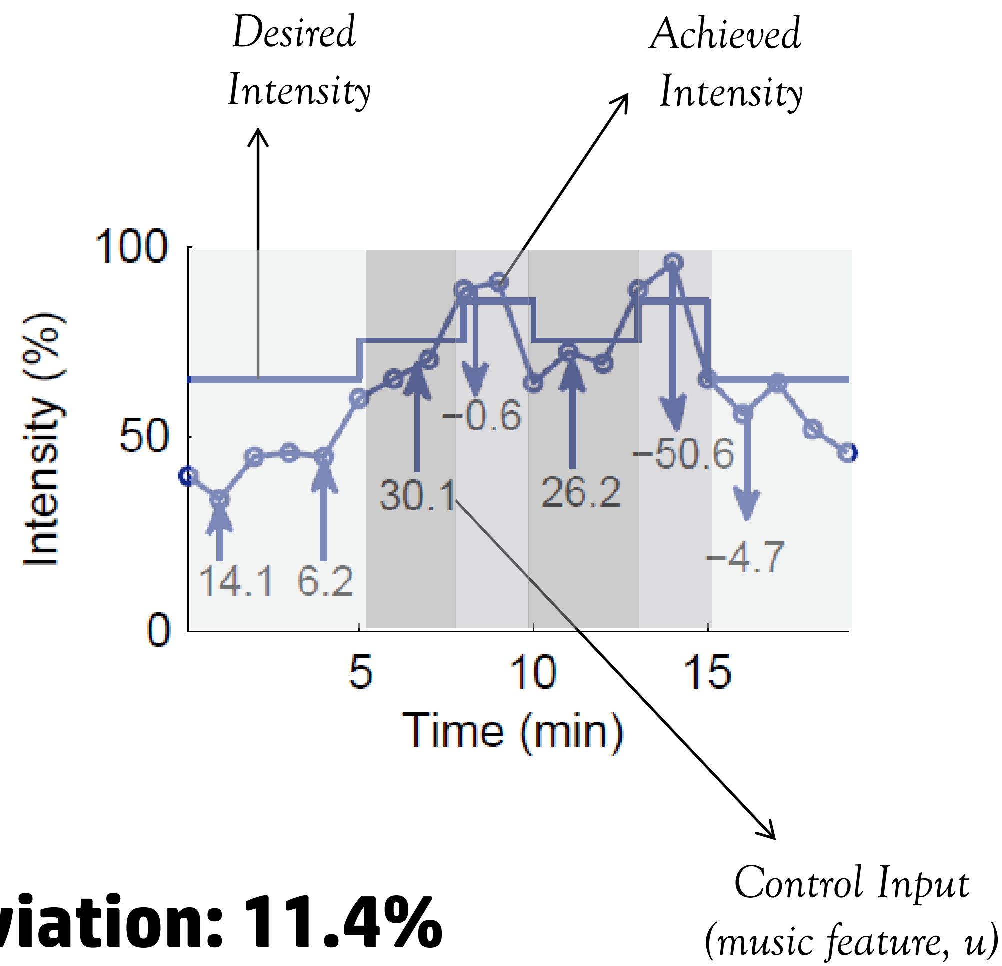


$$u = [\alpha_1\ \alpha_2\ \alpha_3] \text{ x } [Tempo\ Pitch\ Energy]^T$$

Use Case – Cardio Exercise Program

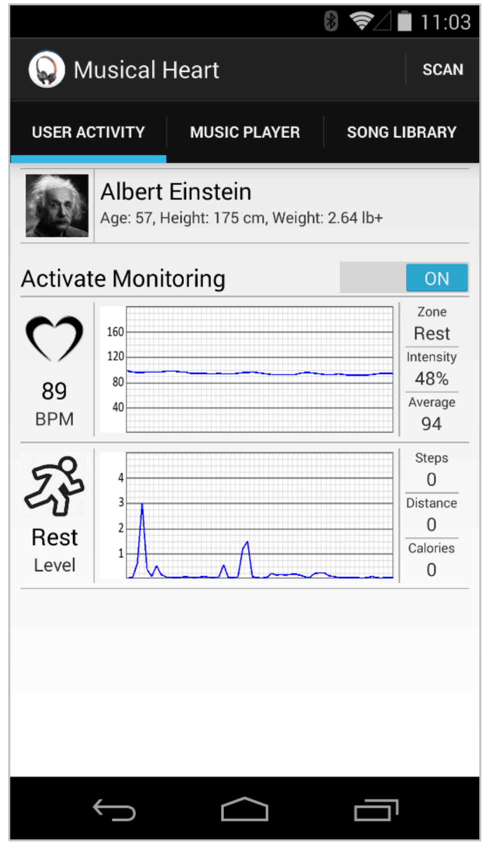
Cardio Chart

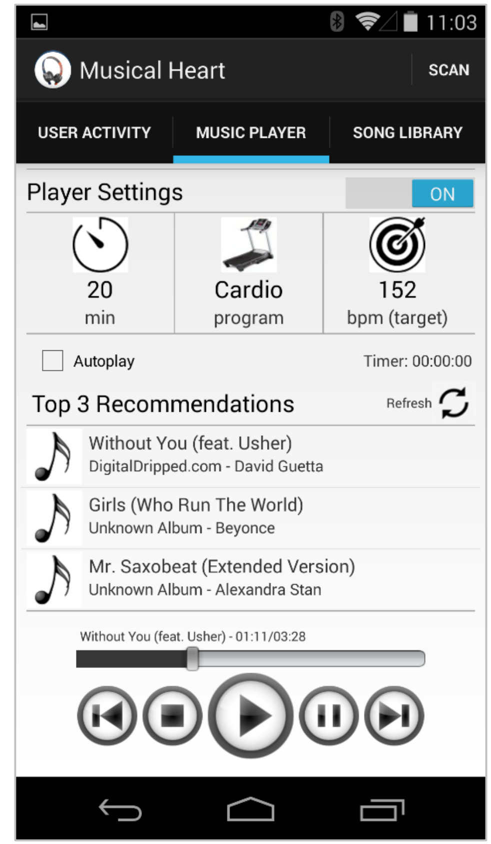
Time	Desired Intensity (%)
5 min	65%
3 min	75%
2 min	85%
3 min	75%
2 min	85%
5 min	65%



Avg. Deviation: 11.4%

Download Musical Heart 2.0





www.cs.virginia.edu/~smn8z/musicalheart.html

Thank You

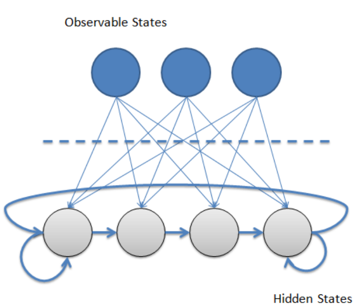
Typing Finger Detector's Accuracy

Comparison of different classifiers

Setup – Classifier Configurations

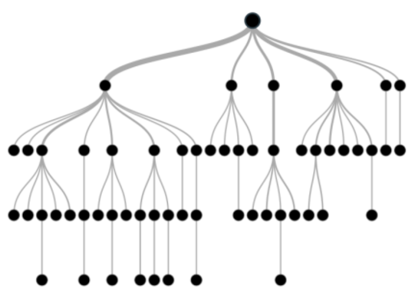
HMM

- Empirical Dataset
- 1000 training iterations
- Randomized initialization
- Repeated 10 times
- 70% training, 30% test



Decision Tree

- Empirical Dataset
- Quantized Features:
  - Proximity Values
  - 3 axis Acceleration



Naïve Bayesian

- Empirical Dataset
- Quantized Features:
  - Proximity Values
  - 3 axis Acceleration

$$P(C \mid X_1, X_2, \ldots, X_n) = \frac{P(X_1, X_2, \ldots, X_n \mid C)\, P(C)}{P(X_1, X_2, \ldots, X_n)}$$

Typing Finger Detector's Accuracy

Comparison of different classifiers

Result – Accuracy of HMM, Decision Tree, and Naïve Bayesian