Computational Jewelry for Mobile Health: the Amulet

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***Clemson University and †Dartmouth College**

amulet-project.org

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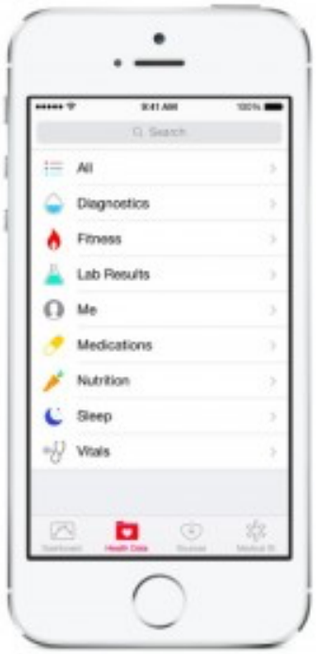
mHealth

The use of mobile computing and communications technology in the delivery of healthcare or collection of health information.

mHealth devices are emerging



sensor clothing

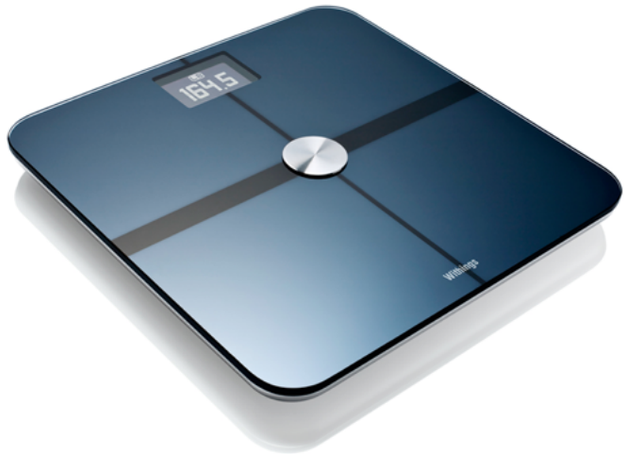
smartsensing.fr

smart inhaler

ECG patch

pillbox

Shared sensors, environment sensors



Withings wireless body scale

Caliber III
(temperature and humidity)

Wireless Heart Rate Monitor
(ProForm AccuRate)

Blood Pressure Monitor
(Omron M10)

Wrist-wearables

Wristbands

Long lived wearables usually for fitness sensing, with longer lifetimes, but closed source and hardware.

Smartwatches

Very flexible development platforms, with short lifetime, often closed operating systems and hardware.

Tradeoffs

Wristbands

Pros:

- Long lifetime

Cons:

- Closed platform
- Not flexible

Smartwatches

Pros:

- Flexibility

Cons:

- Closed hardware or software
- Short lifetimes

Shortcomings

- Closed/inflexible platforms limit research potential
- Short battery life limits long-term mHealth apps

amulet

Amulet

amulet |ˈamyəlit| – noun
an ornament or small piece of jewelry
thought to give protection against evil,
danger, or disease.

Amulet – the big picture

App Developer

app source

Amulet Cloud

app recommendations

Clinician

customized & signed firmware

data upload

ECG and Breathing

GSR and Movement

InsulinPump Implant

Movement Sensors

Patient

amulet

companion smartphone

See amulet-project.org

Design goals

- **Multiple applications** – Multiple developers
- **Built-in security** – app isolation
- **Long battery lifetime – weeks or months!**
- **Developer tools for energy optimization**
- **Usable** – for wearer, researcher, developer
- **Open source** and **open hardware**

Amulet device

Amulet Device

Version Kite.C (Mar'17)

Sensors
- 3-axis gyroscope, ST Electronics L3GD20H
- 3-axis nano-power accelerometer, Analog ADXL362
- Ambient light, UVA/B, temp, sound, battery

Computing
- Nordic nRF51822, ARM Cortex M0, 32K RAM, 256K FLASH
- TI MSP430FR5989, 2KB SRAM, 128KB FRAM
- microSD card slot

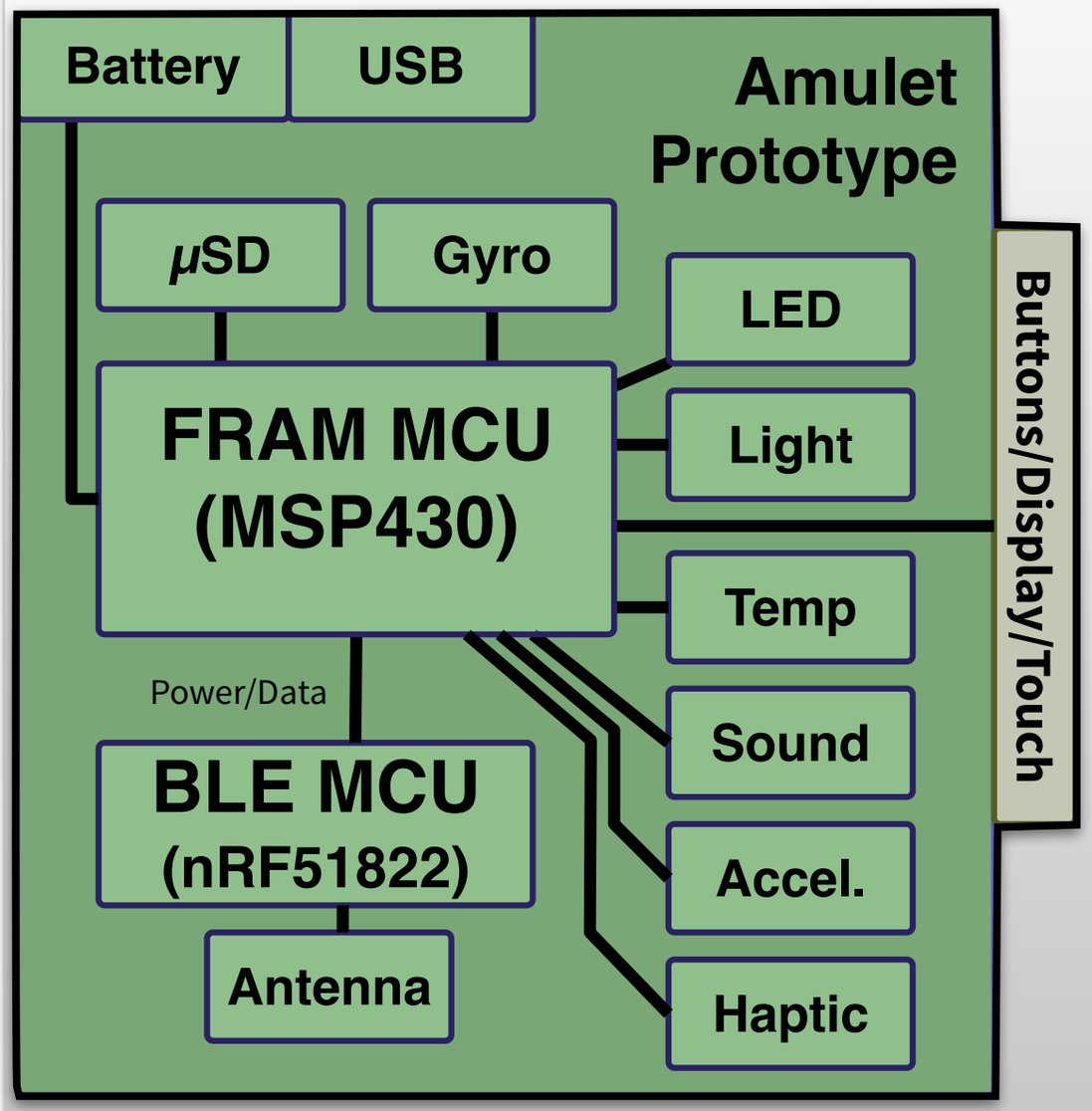
Network
- BLE radio (Central & Peripheral)
- Supported protocols: heartrate, battery, running services

Output
- Monochrome 128x128 Sharp Memory LCD
- two single color LEDs
- haptic feedback via vibrator motor

Input
- two buttons
- capacitive touch slider
- accelerometer

Battery
- Polymer Li-Ion,110 mAh, 3.7V, MCP73831 recharge

Amulet Device



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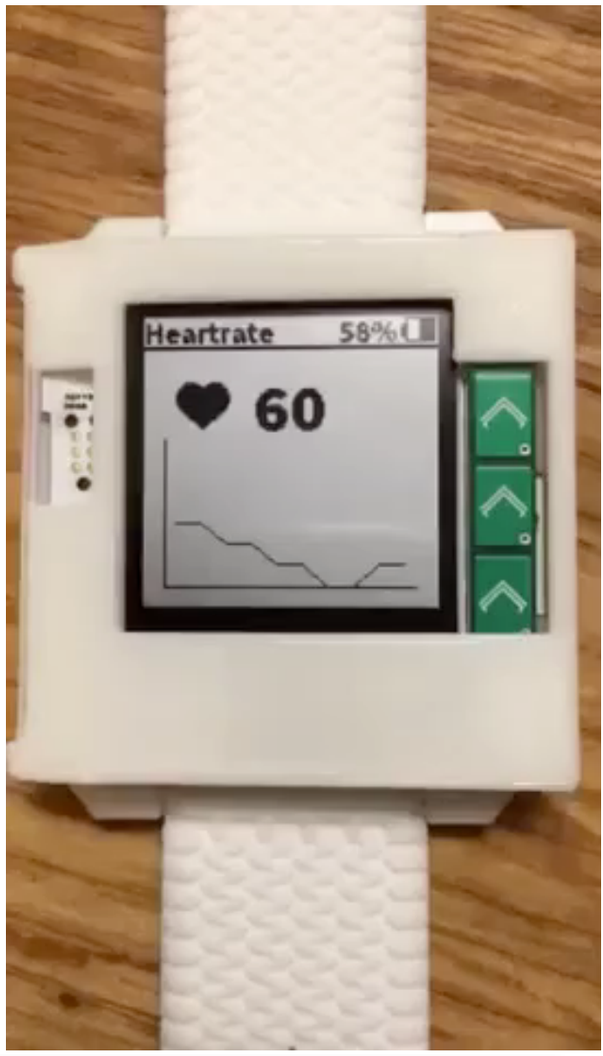
Amulet apps (under development)

- **Stress monitoring**
  - internal (motion) and external (GSR, ECG) sensors
  - computes and logs the wearer's stress level
  - later, creative intervention at times of stress
- **Heart rate** (wireless ECG sensor)
- **Activity monitoring** (accelerometer)
- **Theraband** (force sensor)
- **Fall detection** (accelerometer)
- **Sun exposure** (light sensor)
- **EMA** for self-report information



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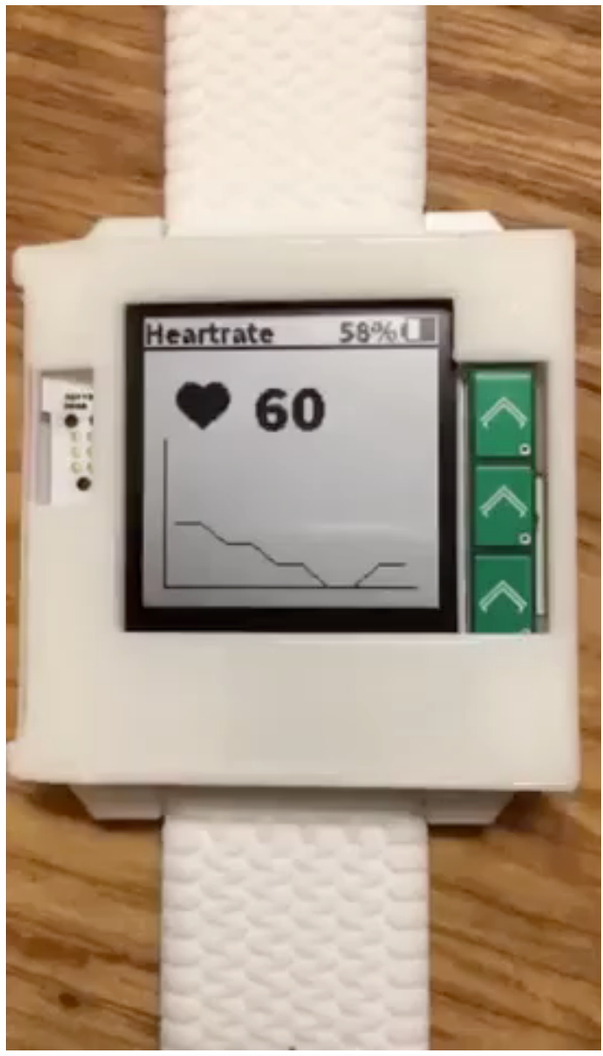
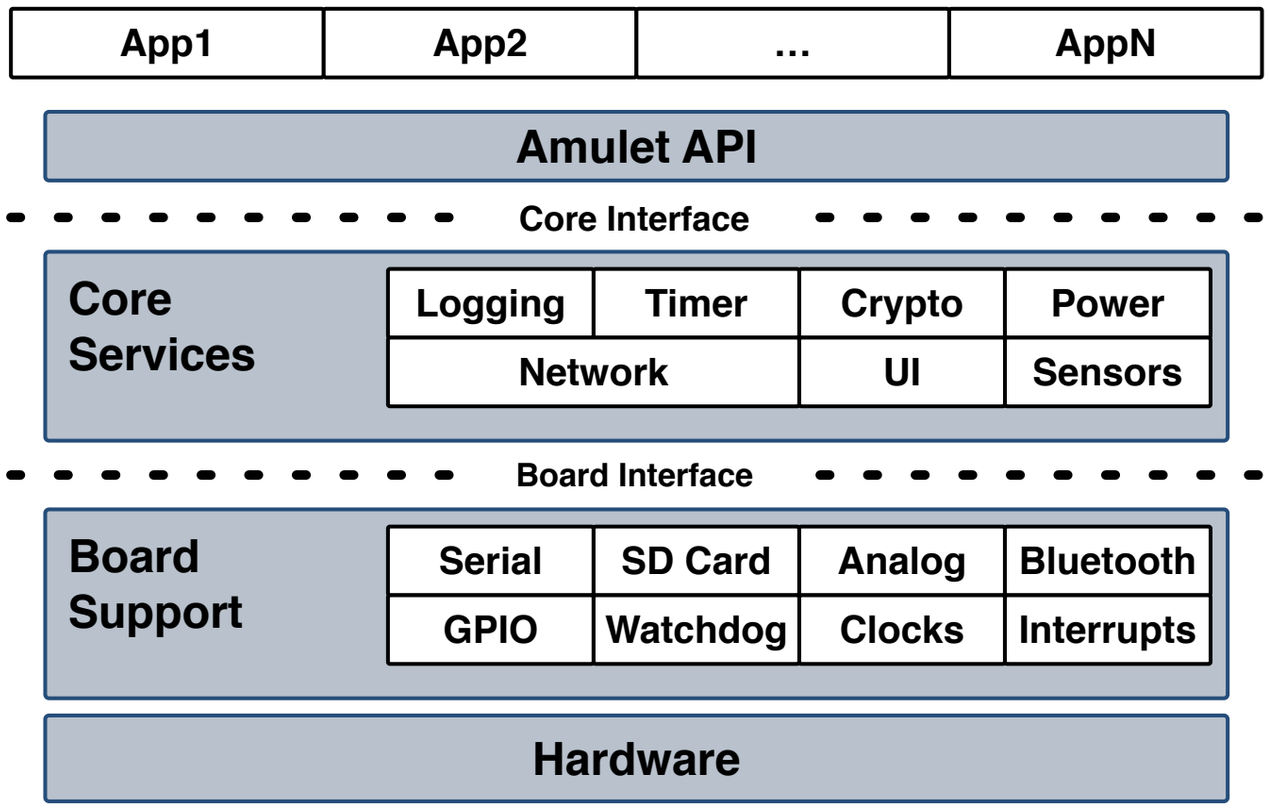


Amulet-OS

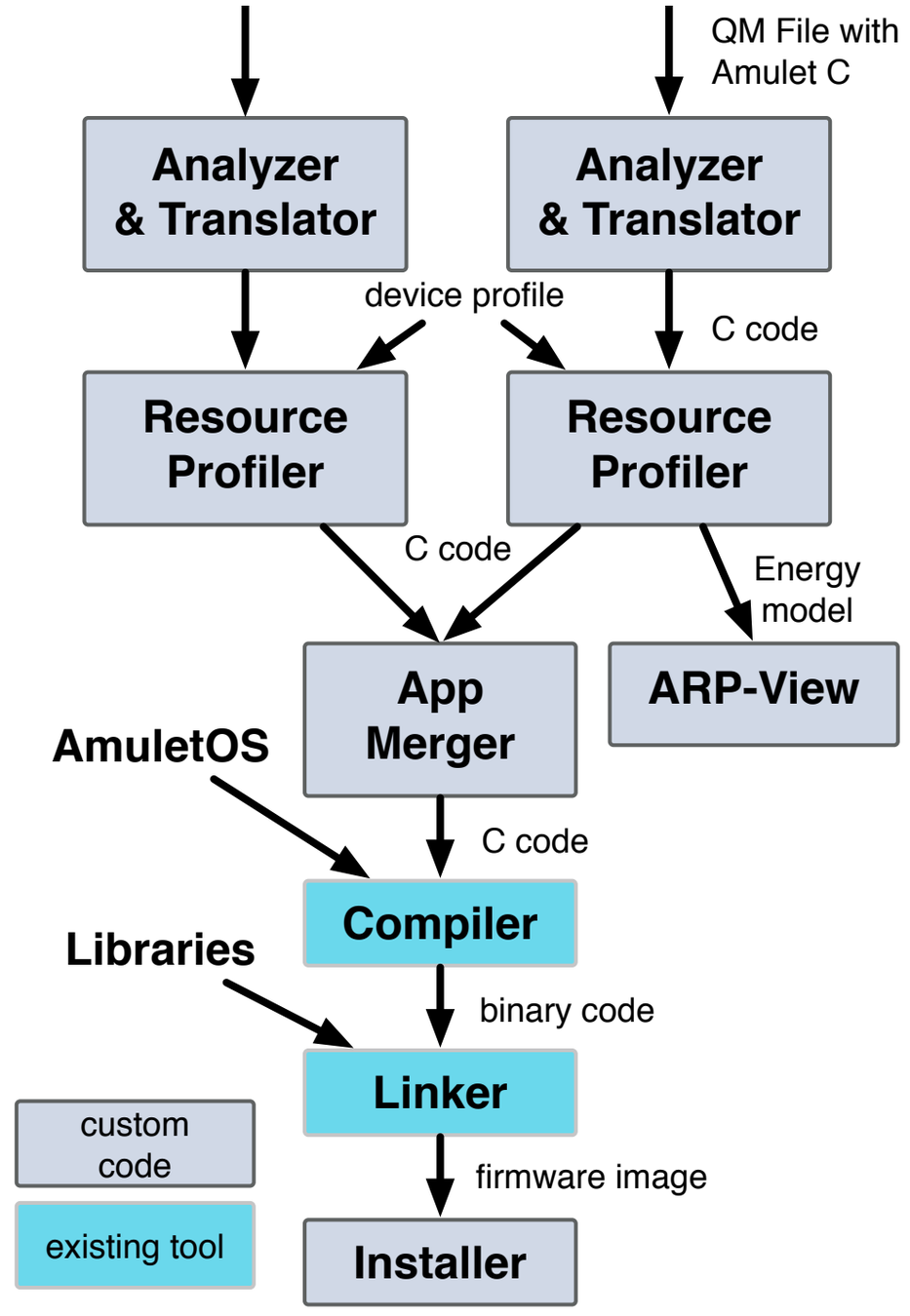
API allows apps to subscribe to sensors, log data, and interact with the wearer.




```
...
void AmuletSubscribeInternalSensor(
    uint8_t sensor_id);
uint16_t AmuletGetHR();
uint8_t AmuletGetBatteryLevel();
uint16_t AmuletGetLightLevel();
uint16_t AmuletGetTemperature();
uint16_t AmuletGetAudio();
int16_t AmuletGetAccelX(uint8_t idx);
void AmuletBoldText(uint8_t x, uint8_t y,
     __char_array message);
void AmuletClearRect(int16_t x, int16_t y,
     uint8_t w, uint8_t h);
void AmuletHapticSingleBuzz();
uint8_t AmuletLogAppend(uint8_t log_name,
    __char_array line_contents);
...
```

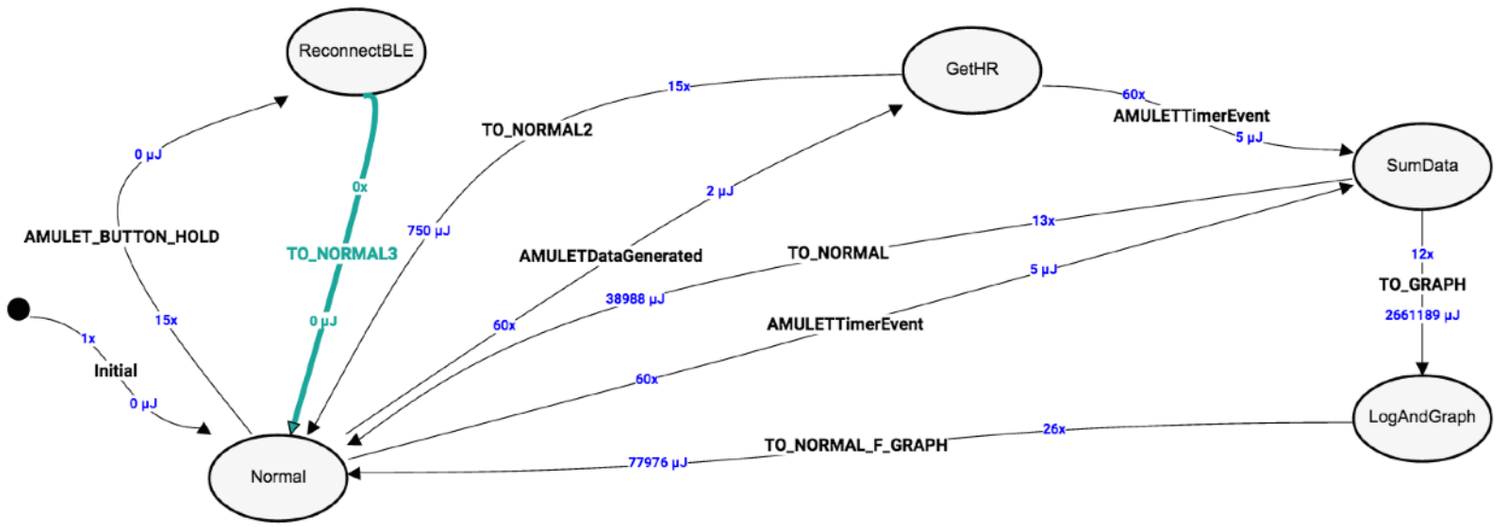
Amulet Firmware Toolchain (AFT)

- Firmware analysis, translation, compile
  - Manage multiple applications
  - Analyze for isolation
  - Profile for energy and memory usage



ARP-View

Please see the Amulet Resource Profiler **documentation** for more info.



Device Selection	Battery Size (mAh)	Total Memory (KB)	Total RAM (KB)	Prediction Method
Zyp Prototype v1.0	110	128.0	2.0	Linear Model

(Single App Model) Selected Application's Battery Impact Per Week — **12.04% (58 day lifetime)**

Memory Use (FRAM)
*(67.71 KB System + **0.62** KB Heartrate) / 128 KB Total*

Max Ram Use (SRAM)
*(1032 B System + **227** B Heartrate) / 2048 B Total*

(Multi App Model) System-wide Battery Impact Per Week — **14.20% (49 day lifetime)**

Memory Use (FRAM)
(67.71 KB System + 0.62 KB Heartrate + 2.07 KB FallDetection + 0.69 KB Temperature + 1.15 KB Clock) / 128 KB Total

Max Ram Use (SRAM)
(1032 B System + 227 B Heartrate + 24 B FallDetection + 55 B Temperature + 32 B Clock) / 2048 B Total

Amulet Resource Profiler

Select Application

Heart Rate Log

Displays heart rate in realtime, summarizes this data in a bar graph, and also logs the data to the SD card every minute. This app communicates with an external BLE sensor such as the Zephyr or Mio.

Select Timescale

Events Per Hour

Move slider(s) to determine the number of **events per hour** of th type specified.

LogAndGraph->TO_NORMAL_F_GRAPH->Normal

ReconnectBLE->TO_NORMAL3->Normal

SumData->TO_GRAPH->LogAndGraph

SumData->TO_NORMAL->Normal

GetHR->AMULETTimerEvent->SumData

GetHR->TO_NORMAL2->Normal

Normal->AMULET_BUTTON_HOLD->ReconnectBLE

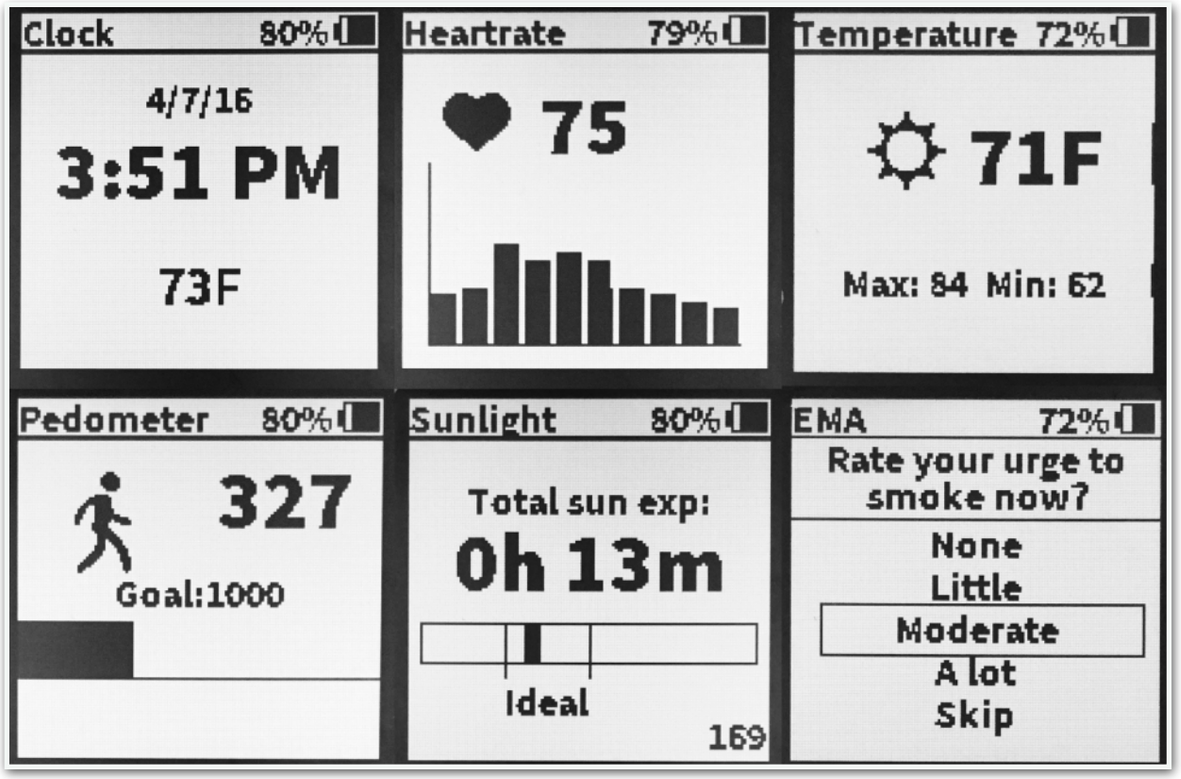
Normal->AMULETTimerEvent->SumData

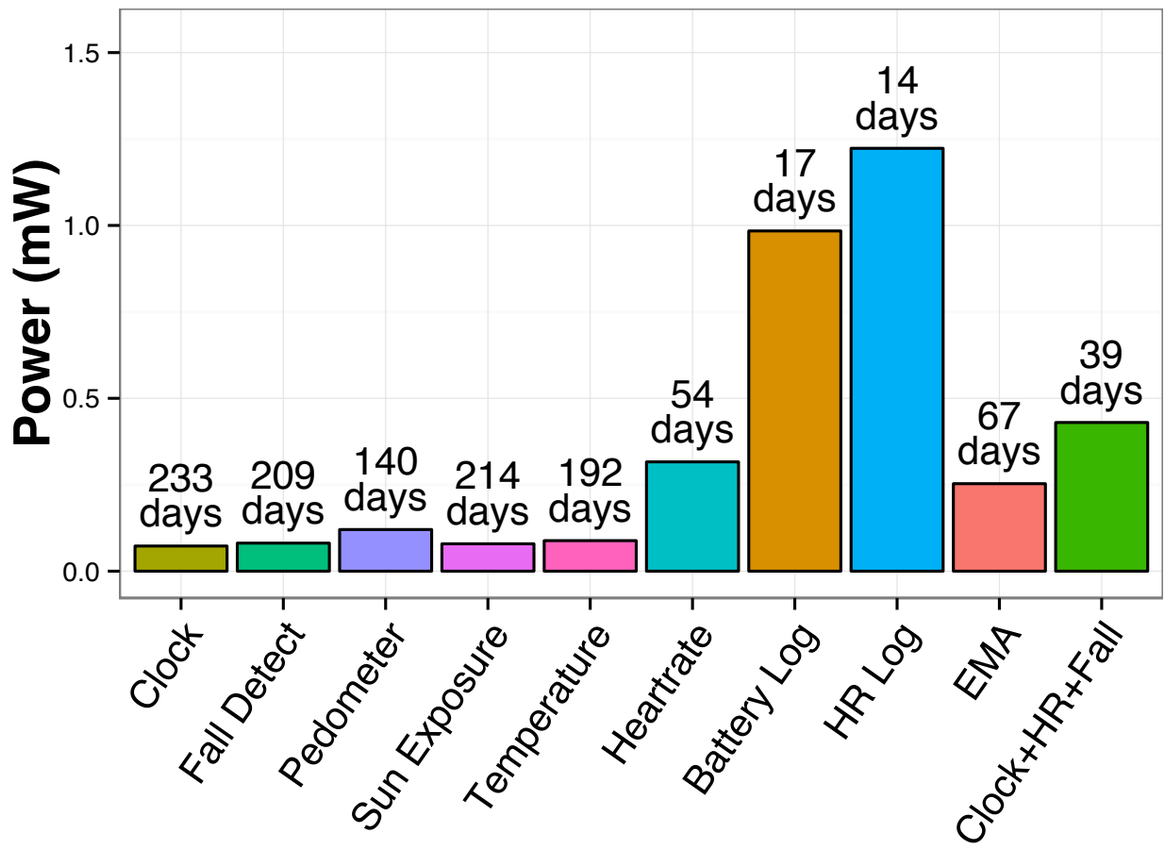
Normal->AMULETDataGenerated_HR->GetHR

Evaluation

Battery lifetimes ranging from 2 weeks to 8 months.

Battery Lifetime





Human Factors Considerations

Human Factors Considerations in the Design of Wearable Devices

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Clemson – South Carolina – United States
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Wearable devices have great potential to support several application domains ranging from medical and safety critical, to leisure and entertainment. Wearable devices' solutions are promising, and extensive research has been conducted in this domain since the early 90's. However most of these works focuses on the feasibility of individual solutions. As such, the human aspects are often neglected, which can decrease not only the acceptance levels for novel devices, but also their sustained engagement. To facilitate the consideration of human factors in the early design stage, we present and define a list of 20 human-centered design principles. We explain how each principle can be incorporated during the design phase of the wearable device creation process. By adopting these principles, we expect practitioners to achieve better wearable solutions, improving the user acceptance, satisfaction and engagement for novel applications.

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Human Factors Considerations

- *Human Factors Considerations in the Design of Wearable Devices.*
- *Smart Wearables or Dumb Wearables?: Understanding how Context Impacts the UX in Wrist Worn Interaction.*
- *Users' Privacy Concerns About Wearables: impact of form factor, sensors and type of data collected.*
- *Micro Interactions and Multi dimensional Graphical User Interfaces in the Design of Wrist-Worn Wearables.*
- *Design Recommendations to Improve the User Interaction with Wrist Worn Devices.*
- *Users' Privacy Concerns About Wearables: impact of form factor, sensors and type of data collected.*

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Iterative pilot deployments

2016: monitoring participants' stress

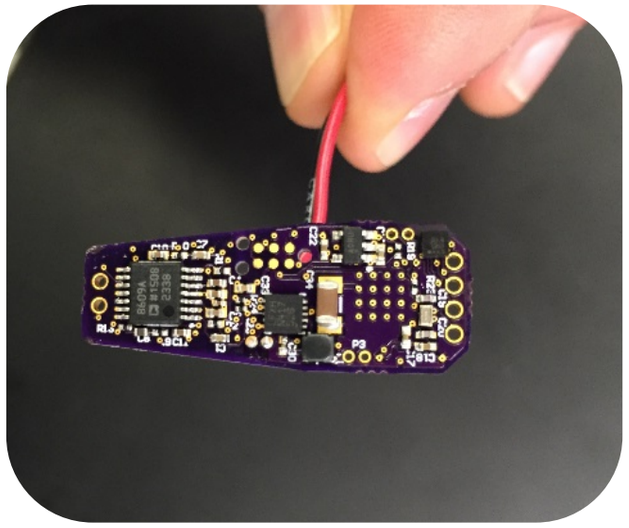
- monitored heart rate using BLE-connected HR sensor
- presented surveys at intervals during the day
- recorded survey responses and heart RRI data
- 6 participants, 1 week, 48 hours of deployment
- usability survey informed future hardware revs

2017: additional sensor for electrodermal activity

- 26 participants (so far), 72 hours of deployment

EDA sensor wristband

- Electro-dermal activity (aka GSR)
- Custom low-power board in a Fitbit band
- Records EDA values for multiple days




Heartrate
102
EMA
Rate your urge to smoke now?
None
Little
Moderate
A lot
Skip
Clock
11/14/16
5:27 PM
71F

Summary

- **Secure, multi-application platform**
- **Open hardware and software**
- **Great battery lifetime –** 2 weeks to 8 months
- **Energy modeling tool predicts lifetime**
- **Usable by users, researchers, and developers**

- **Papers and downloads at amulet-project.org**

Open-source @ amulet-project.org

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Releases Tags

Latest release

1.1

e898476

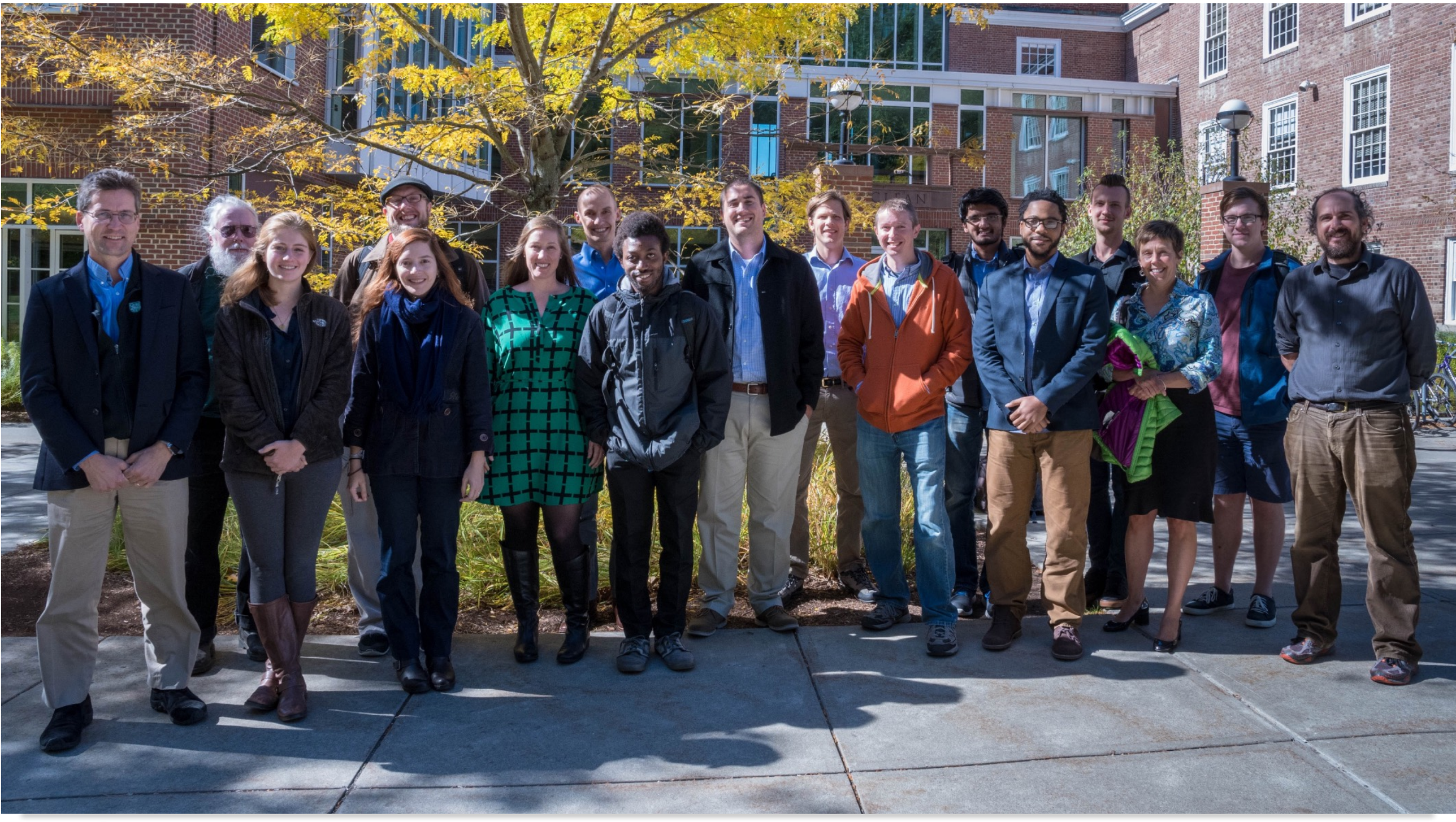
Amulet 1.1

tahardi released this 12 hours ago

Hardware Revisions

- Changed from spring terminals to SPI-BI-WIRE POGO pin connector for programming both the MSP430 and nRF51822
- Repositioned the LCD screen to provide more room for the programmer ports and LEDs
- Broke out UART TX/RX lines for debugging the nRF51822
- Complete case redesign to better fit the mother-daughter boards, buttons, and LCD screen
- Replaced the 4 pin charging connector with a more sturdy USB charging port

Amulet team



Amulet team

- Collaborators include John Batsis, George Boateng, Benjamin Buck (Clemson), Kelly Caine (Clemson), Eric Chen, Yining Chen, Summer Cook, Angela Dalton, Kevin Freeman (Clemson), Bhargav Golla (Clemson), Emily Greene, Ryan Halter, Taylor Hardin, David Harmon, Steven Hearndon (Clemson), Josiah Hester (Clemson), Micah Johnson, Anna Knowles, David Kotz, Stephanie Lewia, Sarah Lord, Byron Lowens (Clemson), Andrés Molina-Markham, Varun Mishra, Vivian Motti (GMU), Emma Oberstein, Travis Peters, Ron Peterson, Tim Pierson, Gunnar Pope, Patrick Proctor, Joe Skinner, Morgan Sorbaro, Jacob Sorber (Clemson), Kevin Storer, Emily Wechsler, Tianlong Yun (Google), Alexandra Zagaria.

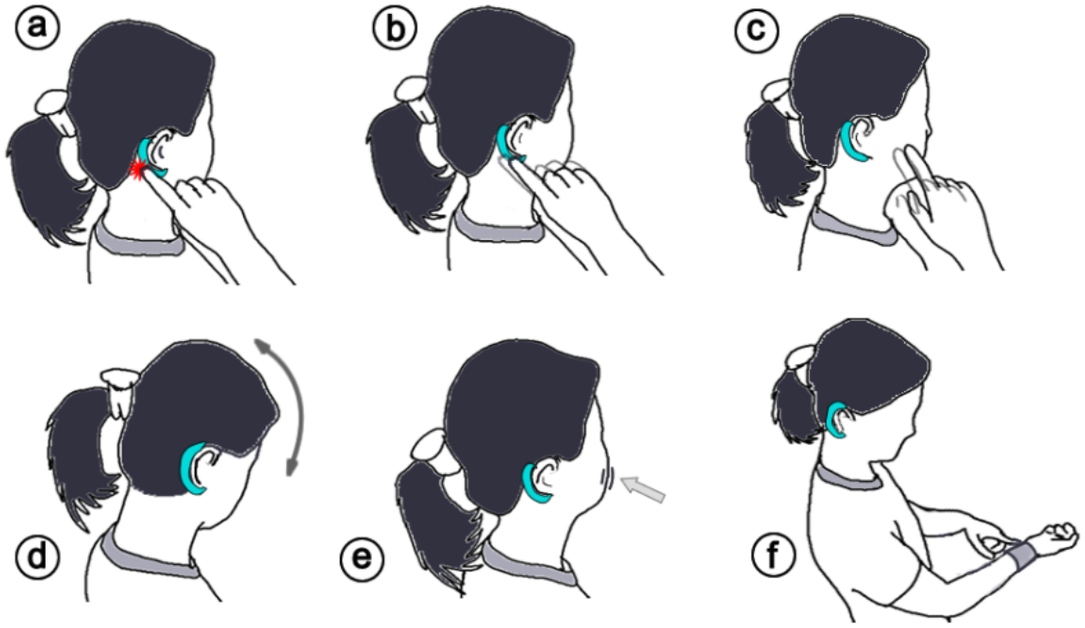
Institute for Security, Technology, and Society (ISTS)

Computational Jewelry

Auracle: a wearable device for detecting and monitoring eating behavior

- **Motivation**: Use technology to track and understand eating behavior, in support of eating-behavior research.
- **Problem**: Health science has no effective means for automatically measuring eating behavior in real life.
- **Goal**: Develop a wearable earpiece to monitor eating through a waking day, unobtrusively, in free-living conditions.

Contact microphone



Potential user-interface modalities

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