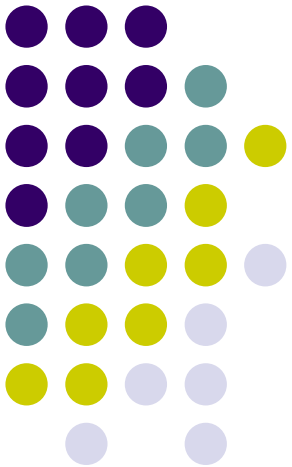
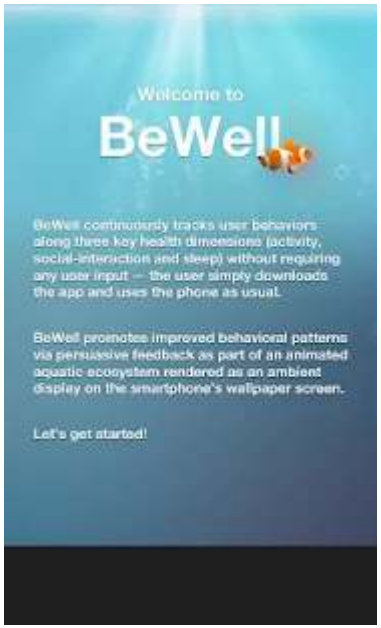
Unobtrusive Sleep Monitoring using Smartphones

Ying Wang



- https://play.google.com/store/apps/details?id=org.bewellapp



About the Application

- **Sleep quality and quantity impacts personal health.**

--blood pressure

--high stress

--anxiety

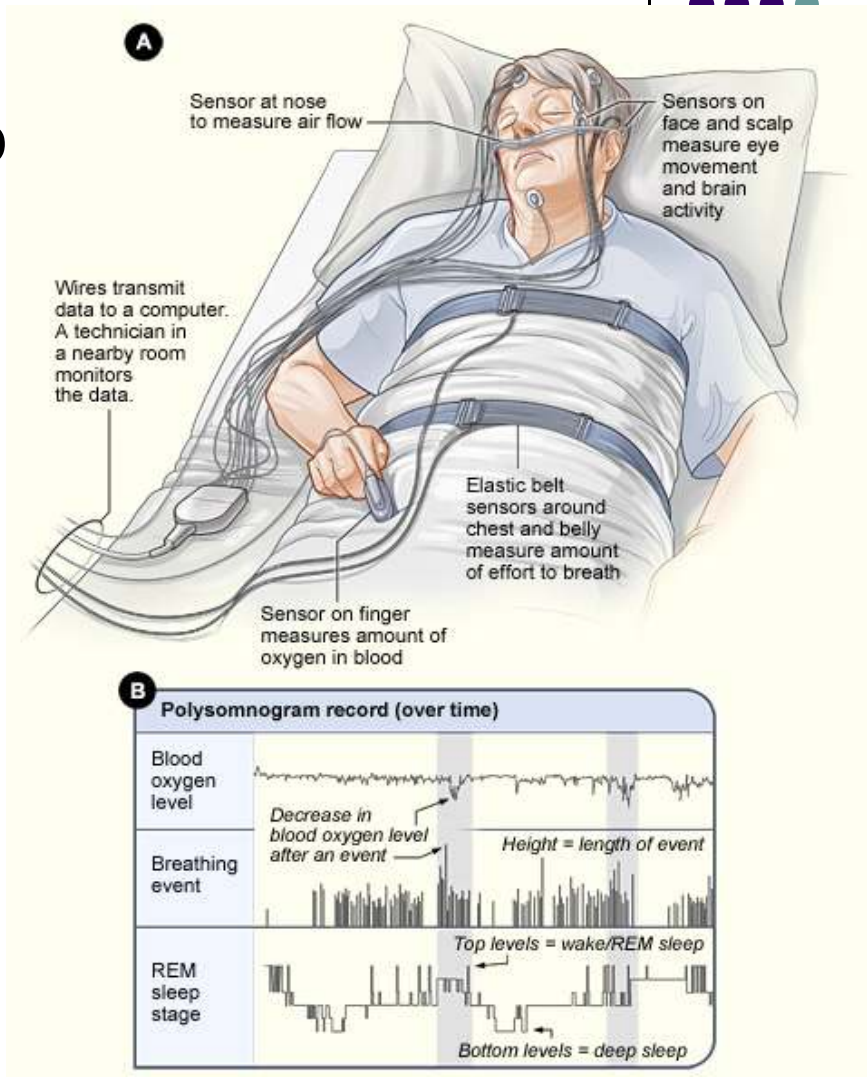
--diabetes

--high blood pressure

Motivation

- Existing Sleep Monito

A polysomnogram mon



Complexity

Cost

Not impractical

Motivation

- Commercial Wearable Devices

Intrusive and cumbersome

Motivation

- Best Effort Sleep (BES) Model
- Just Use a Single Phone!
- Benefit:

--No interaction Need

--No wear or special manner

--Practical for large scale sleep monitoring

- Wide-scale of smartphone make it feasible
- Limit : only estimate sleep duration

Vision

- Sleep-with-the-phone(SWP) model

12 Features:

(5 minutes long) four time-domain features

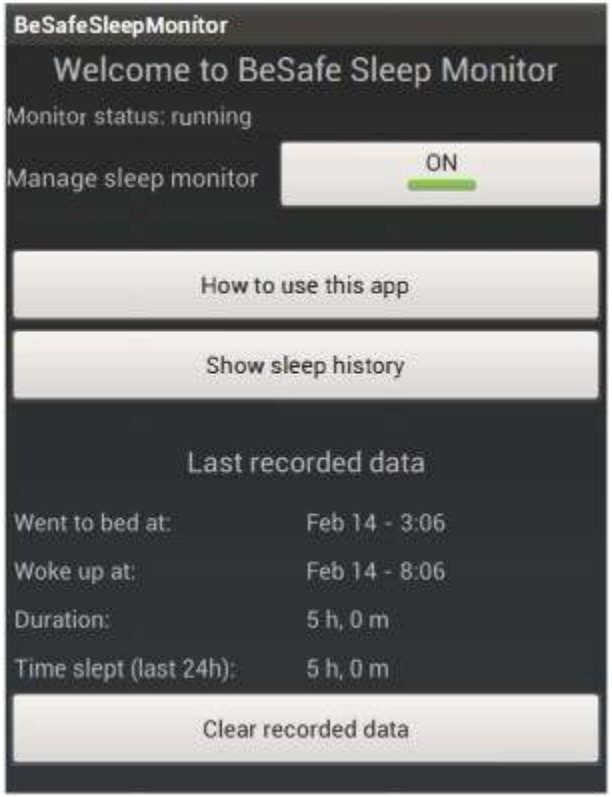
nimum, maximum, root mean square)

*

(x,y,z)

Each time window is classified using

a C4.5 decision tree as implemented by Weka



Relate Work

- **Jawbone Up**

https://jawbone.com/up

Feature

Tracks not only sleep but also physical activity

Infers “lignt” and “deep” sleep

Limitation:

if the user fails to correctly toggle the device between sleep and wake modes the collected sleep data will be incorrect

To collect to review sleep data the user must connect it with either an iOS or Android smartphone

Relate Work

- Zeo Sleep Manager Pro

https://www.youtube.com/watch?v=j3Y7PGhHR20

Feature

Monitor the electrical signals of the brain, muscle contractions and eye movement.

Limitation:

Must put on the headband during sleep

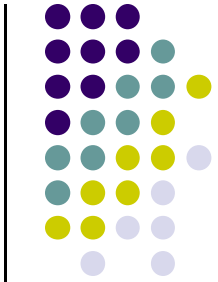
Pair it with a smartphone via bluetooth

ain in place during sleep

ed recharging everyday

Relate Work

- BEST EFFORT SLEEP (BES) MODEL



- The BES model is statistical and has multiple features:

Phone Usage features.

--phone-lock (F2)

--phone-off (F4)

--phone charging (F3)

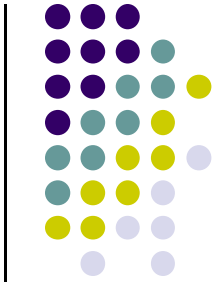
Light feature (FI).

--phone in darkness

--phone in a stationary state (F5)

--phone in a silent environment (F6)

Methodology



BEST EFFORT SLEEP (BES) MODEL

BES combines these 6 features to form a more accurate sleep model and predictor.

- BES assumes that the sleep duration of a person (Sl) is a liner combination of these 6 features:

$$Sl = \sum_{i=1}^{6} a_i * F_i \, , a_i \geq 0$$

- Using 8 subjects for one week to train the BES model.

- BES formalizes the model training process as a nonnegative least-squares regression problem. Specifically, by solving:

$$\min_{a_i} \sum_{j=1}^{4} (Sl^j - \sum_{i=1}^{6} a_i * {F_i}^j)^2$$

Methodology

Feature	Coefficient
Light (F_1)	0.0415
Phone-lock (F_2)	0.0512
Phone-off (F_3)	0.0000
Phone-charging (F_4)	0.0469
Stationary (F_5)	0.5445
Silence (F_6)	0.3484

TABLE I: Weight coefficients for each feature in BES

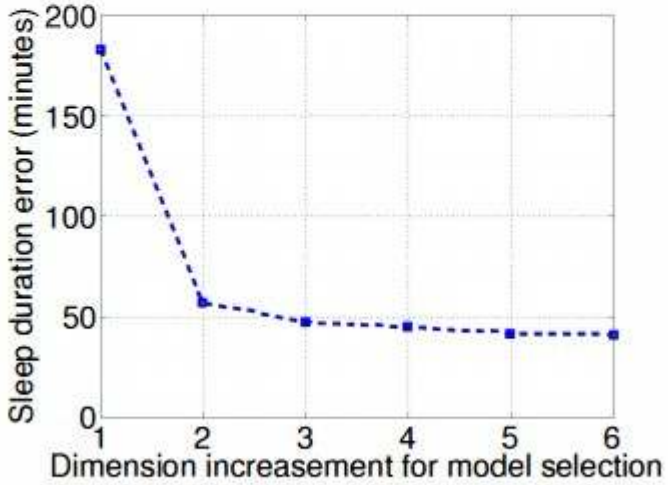


Fig. 2: The reduction in sleep duration error for BES by incrementally adding stationary, silence, phone-lock, phone-charging, light and phone-off features, respectively.

Results

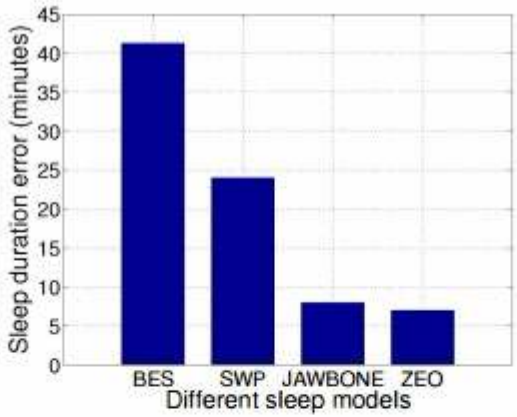


Fig. 3: Overall sleep duration error for BES compared to the three alternative sleep monitoring systems (SWP, Jawbone, Zeo).

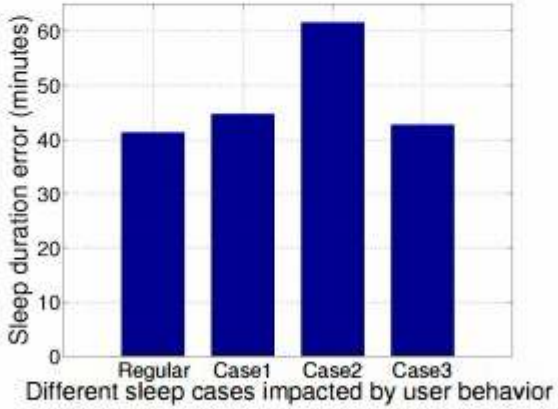


Fig. 4: BES sleep duration error when users behave as expected ("regular") compared to three examples of atypical sleep behavior (i.e., corner cases). Specifically, these behaviors are: Case1 – user sleeps with the room lights on; Case2 – user has a prolonged nap during the day; Case3 – user fails to recharge their phone.

Results

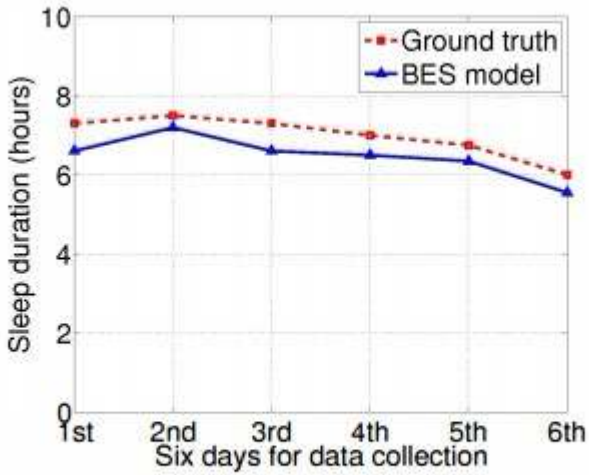


Fig. 5: Comparison of estimated and actual sleep duration under BES for one representative study subject.

Results

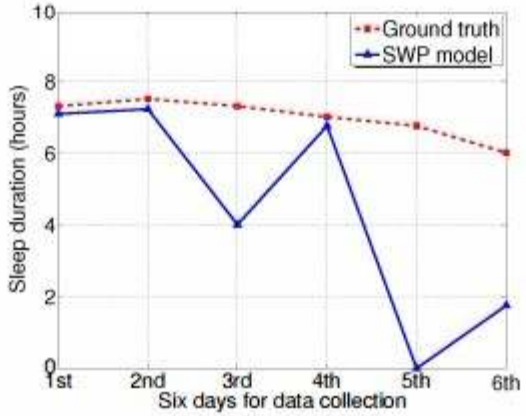


Fig. 6: Comparison of estimated and actual sleep duration under SWP for one representative study subject.

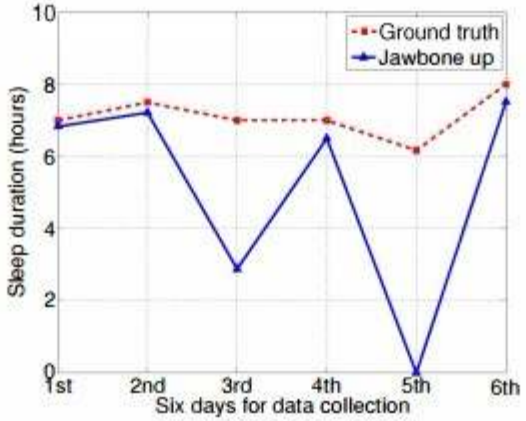


Fig. 7: Comparison of estimated and actual sleep duration for one representative study subject while using the Jawbone Up device.

Results

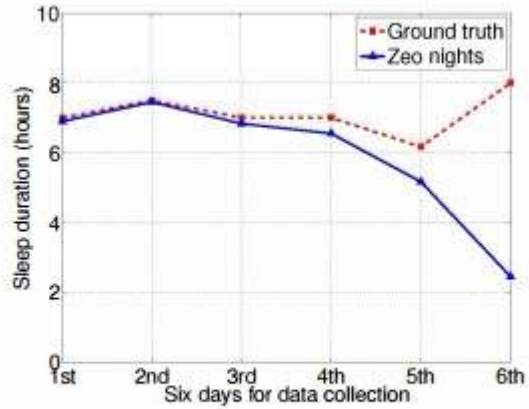


Fig. 8: Comparison of estimated and actual sleep duration for one representative study subject while using the Zeo Sleep Manager Pro device.

Results

Sleep System	Q1	Q2	Q3	Q4	Q5	Q6	Q7
BES	5	5	4.5	4.5	4	2.75	4
SWP	3	2.5	3	3	3.25	2	2.25
Jawbone	3.5	4	4	4	4	5	4
Zeo	1.75	2.75	3.5	2	2.5	3.25	2.75

TABLE II: Summary of User Experience Survey

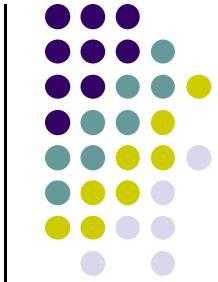
Results

- On-body Sensors vs. Smartphone Sensing

1) User Burden
2) Sleep Data
3) User Feedback
4) Cost

Conclusion

- Thanks!



Discussion