Using iOS for Inconspicuous Data Collection: A Real-World Assessment

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Yuuki Nishiyama[1], Denzil Ferreira[2], Wataru Sasaki[3], Tadashi Okoshi[3], Jin Nakazawa[3], Anind K. Dey[4], and Kaoru Sezaki[1]

[1]The University of Tokyo, Japan
[2]University of Oulu, Finland
[3]Keio University, Japan
[4]University of Washington, Seattle, USA

東京大学
生産技術研究所
Institute of Industrial Science,
The University of Tokyo

Abstract

Background: Mobile Crowd Sensing (MCS) tool allows us to collecting multiple sensor data (such as accelerometer, gyroscope, and GPS) from off-the-shelf smartphone inconspicuously

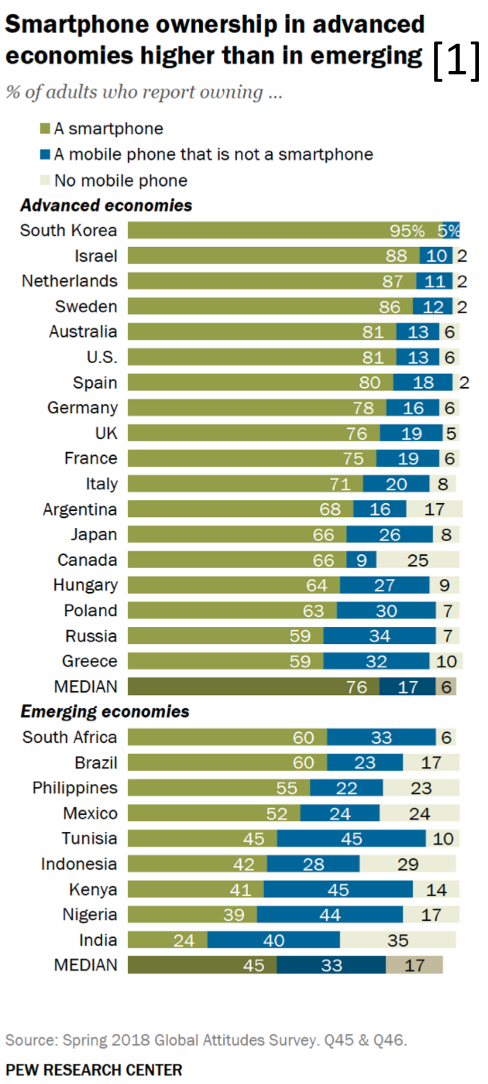
Issue: Although several MCS tools are proposed and that have a lab-level benchmark the performance in a practical study condition is scarce.

Approach: In this study, we assess the quality of data collection of a MCS tool for iOS (namely AWARE-iOS), installed on off-the-shelf smartphones with ***9 participants for a week in-the-wild condition***.

Result: More than 97% of sensor data, provided by hardware sensors (i.e., accelerometer, location, and pedometer sensor), is successfully collected in the wild condition, unless a user explicitly quits the MCS tool.

Background

- Smartphone has spread rapidly all over the world[1]
- **Mobile Crowd Sensing (MCS)** is a research method to understand human activities/context by using collected sensor data from distributed smartphones [2-4]
  - Tracking mental-health, heavy drink, and marijuana usage
- **Mobile Sensing Framework**[5-7] allow us to collect sensor data quickly
  - Support multiple sensors (accelerometer, gyroscope, GPS, and more)
  - Survey (Experience Sampling Method: ESM)
  - Inconspicuous data collection



[1] Smartphone Ownership Is Growing Rapidly Around the World, but Not Always Equally, https://www.pewresearch.org/global/2019/02/05/smartphone-ownership-is-growing-rapidly-around-the-world-but-not-always-equally/
[2] Lane, N., et al.: A survey of mobile phone sensing. IEEE Commun. Mag. 48(9), 140–150 (2010)
[3] Wang, R., et al.: StudentLife: assessing mental health, academic performance and behavioral trends of college students using smartphones. In: Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing, pp. 3–14 (2014)
[4] Rachuri, et al.: EmotionSense: a mobile phones based adaptive platform for experimental social psychology research. In: Proceedings of the 12th ACM International Conference on Ubiquitous Computing - Ubicomp 2010, p. 281 (2010)
[5] Ferreira, D., Kostakos, V., Dey, A.K.: AWARE: mobile context instrumentation framework. Front. ICT 2, 6 (2015)
[6] Katevas, K., et al.: SensingKit: evaluating the sensor power consumption in iOS devices. Proceedings - 12th International Conference on Intelligent Environments, IE 2016, pp. 222–225 (2016)
[7] Xiong, H., et al.: Sensus: a cross-platform, general-purpose system for mobile crowdsensing in human-subject studies. In: Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing, pp. 415–426. ACM Press, New York (2016)

Problem

- The latest mobile **OSs aggressively terminate or suspend an application** running in the background for maximizing battery life
- **Existing MCS tools did not assess the performance in the realistic condition** [2,3,4,5]
- The quality of data collection depends greatly on the sensors selected and user compliance

[1]“iOS Crowd-Sensing Won't Hurt a Bit!: AWARE Framework and Sustainable Study Guideline for iOS Platform,” Yuuki Nishiyama, Denzil Ferreira, Yusaku Eigen, Wataru Sasaki, Tadashi Okoshi, Jin Nakazawa, Anind K Dey, and Kaoru Sezaki, In: Streitz, Norbert, Konomi, Shiníchi (Ed.): Distributed, Ambient and Pervasive Interactions, pp. 223–243, Springer International Publishing, Cham, 2020, ISBN: 978-3-030-50344-4.

Need to assess the performance of MCS tool in realistic conditions

2. Rachuri, et al.: EmotionSense: a mobile phones based adaptive platform for experimental social psychology research. In: Proceedings of the 12th ACM International Conference on Ubiquitous Computing - Ubicomp 2010, p. 281 (2010)
3 Ferreira, D., Kostakos, V., Dey, A.K.: AWARE: mobile context instrumentation framework. Front. ICT 2, 6 (2015)
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Related Works: Mobile Sensing Frameworks

Name	OS	Structure			Functions		Performance Evaluation		
		Client	Library	Server	Sensor	Survey	Battery	I/O	Case Study
AWARE-iOS [5]	iOS	✓	✓	✓	✓	✓	✓	✓	△
AWARE-Android [1]	Android	✓	✓	✓	✓	✓	✓		
Sensus [2]	iOS & Android	✓		✓	✓	✓			△
mEMA	iOS & Android	✓		✓	✓	✓			
SensingKit[3]	iOS & Android	✓	✓		✓		✓		
StudentLife[3]	iOS & Android	✓			✓		✓		

1 Ferreira, D., Kostakos, V., Dey, A.K.: AWARE: mobile context instrumentation framework. Front. ICT 2, 6 (2015)
2.Xiong, H., et al.: Sensus: a cross-platform, general-purpose system for mobile crowdsensing in human-subject studies. In: Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing, pp. 415–426. ACM Press, New York (2016
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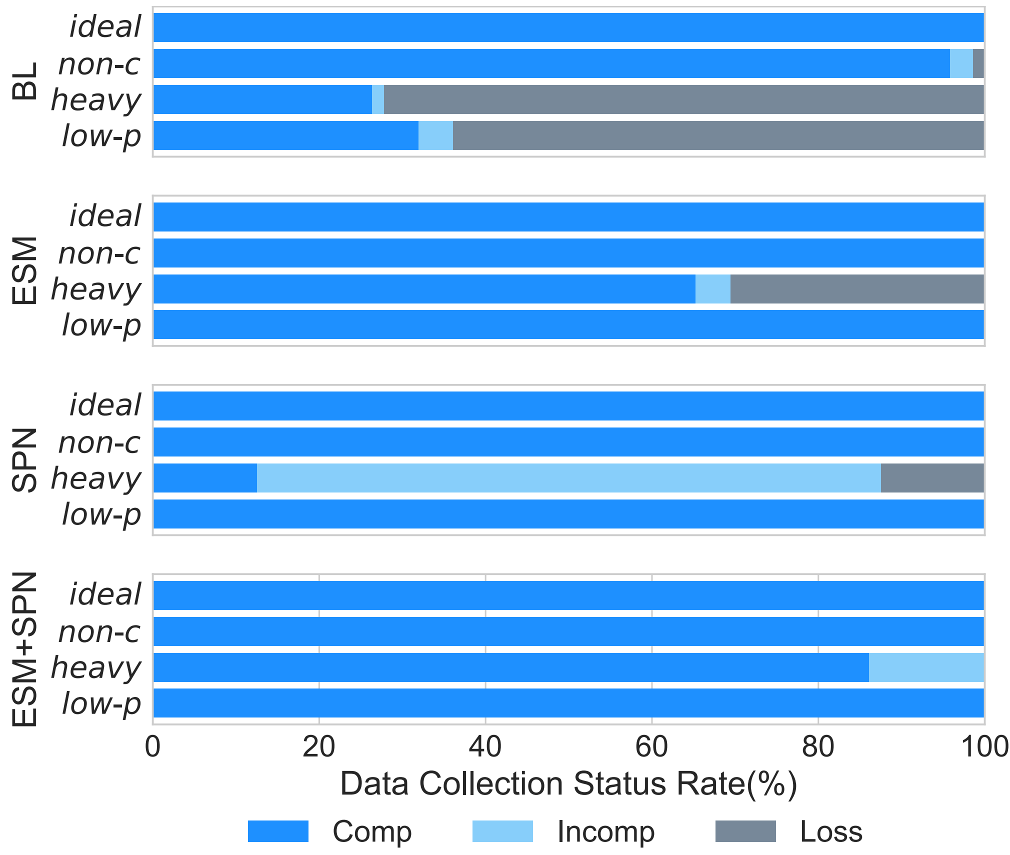
Case Study: Data Collection Rate

- Duration: **3 days**
- Case: **4 cases**
  - **Baseline**
  - **ESM (Experimense Sampling Method):** Take survey 3 times in a day
  - **SPN (Silent Push Notification):** Send a SPN every 30 minute
  - **ESM + SPN**
- Device: **4 iOS Devices**
  - Idle, Non-c, Heavy, Low-p
- Sensors: **6 Sensors**
  - **Locations** (100 m, 3 min.) → 480 records per day
  - **Accelerometer** (5 Hz)
  - **Pedometer** (3 min.)
  - **Weather** (10 min.)
  - **Screen** (eventual)
  - **Battery** (eventual)



Locations

BL > ESM+SPN > SPN > ESM

Ideal > non-c > heavy > low-p

"iOS Crowd-Sensing Won't Hurt a Bit!: AWARE Framework and Sustainable Study Guideline for iOS Platform," Yuuki Nishiyama, Denzil Ferreira, Yusaku Eigen, Wataru Sasaki, Tadashi Okoshi, Jin Nakazawa, Anind K Dey, and Kaoru Sezaki, In: Streitz, Norbert, Konomi, Shiníchi (Ed.): Distributed, Ambient and Pervasive Interactions, pp. 223–243, Springer International Publishing, Cham, 2020, ISBN: 978-3-030-50344-4.

Goal of This Research

"How does a MCS tool work **in-the-wild condition**?"

The result of our previus study
→ The data collection rate is changed depends on conditions (**ESM+SPN** is better condition **in-the-lab study**)

In-the-wild
Data Collection

In-the-wild
Battery Impact

(1) Demonstrate the quality of data collection and battery impact in-the-wild condition for realizing safely data collection
(2) Propose a factor for evaluating the performance of MCS tools

What is *AWARE Framework* ?

An open source mobile sensing framework for multiple platforms

Start MCS by just install the app, and read a QR code!

200+ reseaches citated/used this framework

Open Souce (Apache 2.0) Client (Library & UI) &Server

600+ members

Ferreira, D., Kostakos, V., Dey, A.K. AWARE: mobile context instrumentation framework. Frontiers in ICT (Vol 2, Issue 6), 2015, DOI: 10.3389/fict.2015.00006, https://awareframework.com/

What is AWARE Framework for iOS (AWARE-iOS)?

- Multiple sensors (more than 23 sensors on iOS)
- Schedule/dynamic ESM
- Remote control via SPN
- Resource optimization
- Open source library/client (GitHub and AppStore)

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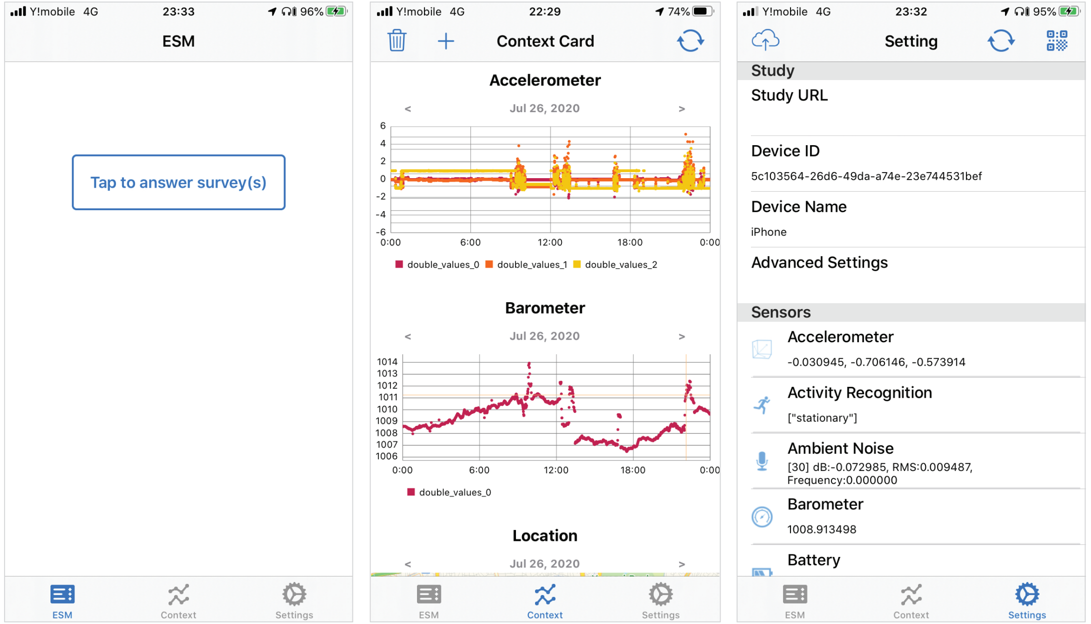
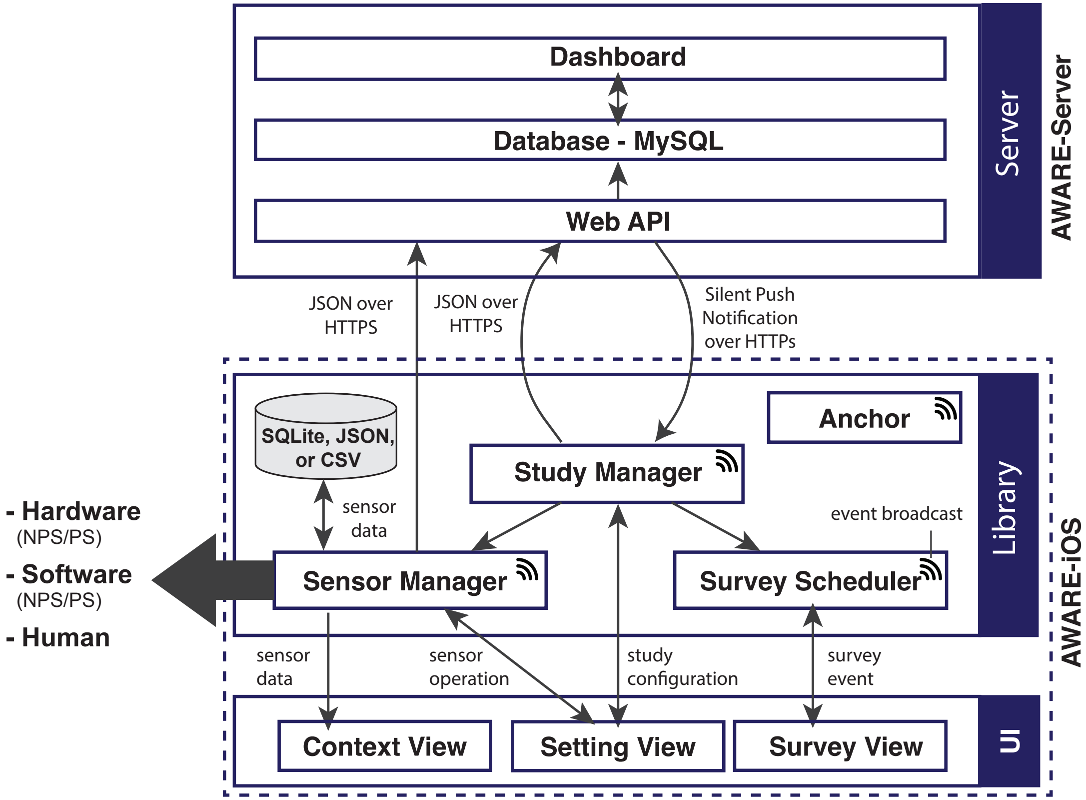


Screenshots of AWARE Client iOS v2



Framework Architecture of AWARE-iOS

Sufficient Sensor Data Collection on Smartphone in-the-wild condition

Data Collection Rate

= Amound of collected data / Estimated amount of sensor data * 100

Battery Impact

= Battery consumotion per hour

Experimental Setup

- Participants: **10 volunteers**
  - Students of Keio University, Japan
  - * A participant dropout during a study
- Duration:
  - 1 week
- Data Collection (same setup with our previous work[1]) :
  - Tool: **AWARE Client iOS V2** on AppStore
  - **7 sensors** as same as our previous work (Pedometer, Location, Accelerometer, Weather, Battery, Screen, and ESM)
  - Smartphone usage log: **SPN, memory warnings, and terminate events**

Participants' Devices

#	Device	OS	RAM	Storage (Free)
D1	iPhone XR	13.3	3GB	128 (2) GB
D2	iPhone XS	13.3.1	4GB	64 (8) GB
D3	iPhone XS	13.3	4GB	64 (1) GB
D4	iPhone XS	13.3	4GB	256 (141) GB
D5	iPhone XS	13.3	4GB	256 (54) GB
D6	iPhone 11	13.3	4GB	128 (63) GB
D7	iPhone 11	13.3.1	4GB	128 (82) GB
D8	iPhone 11	13.3.1	4GB	256 (22) GB
D9	iPhone 11 Pro	13.3.1	4GB	64 (5) GB

Estimated Amount of Sensor Data

Sensor Name	Interval (Accuray)	Hour	Day	Week
SPN	10 min.	2	48	336
ESM	3 times / 1 day	NA	3	21
Location	3 min. (100m)	20	480	3,360
Pedometer	10 min.	6	144	1,008
Accelerometer	5 Hz	18,000	432,000	3,024,000
Weather	10 min.	6	144	1,008

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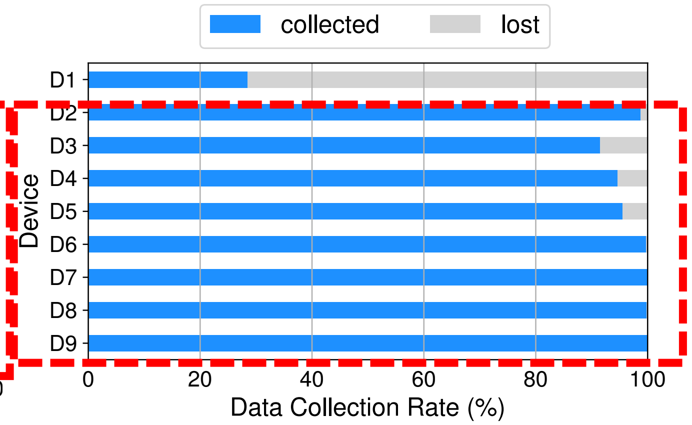
Data Colleration Rate

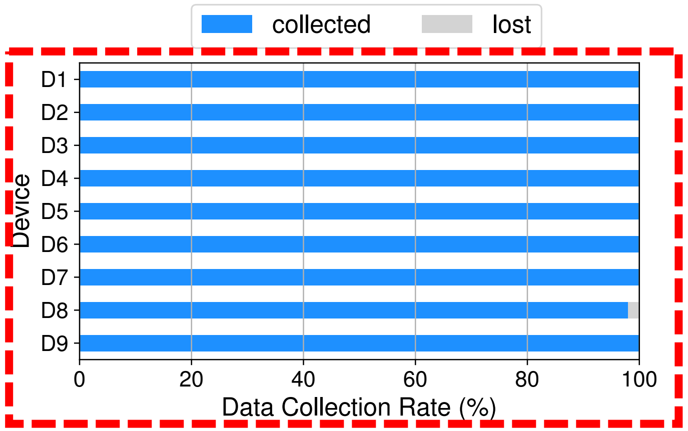
- Except for D1, all devices collected more than 97% of Location and Accelerometer data
- The data losing patter of both sensors is similar

Location



Accelerometer

- 100% of data is collected from all participants' phone (excpet for D8)



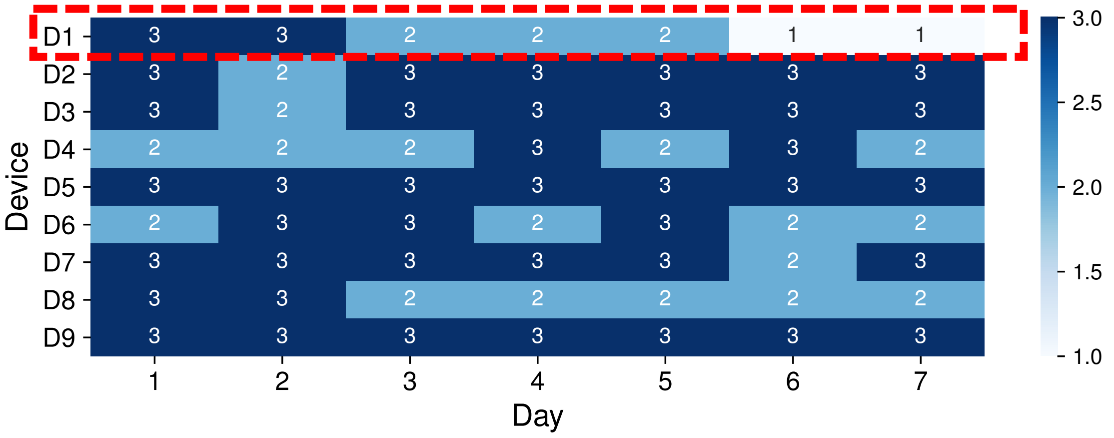
Pedometer

- Except for D1, data collection rate of weather sensor is 80.49 (SD: 10.65)

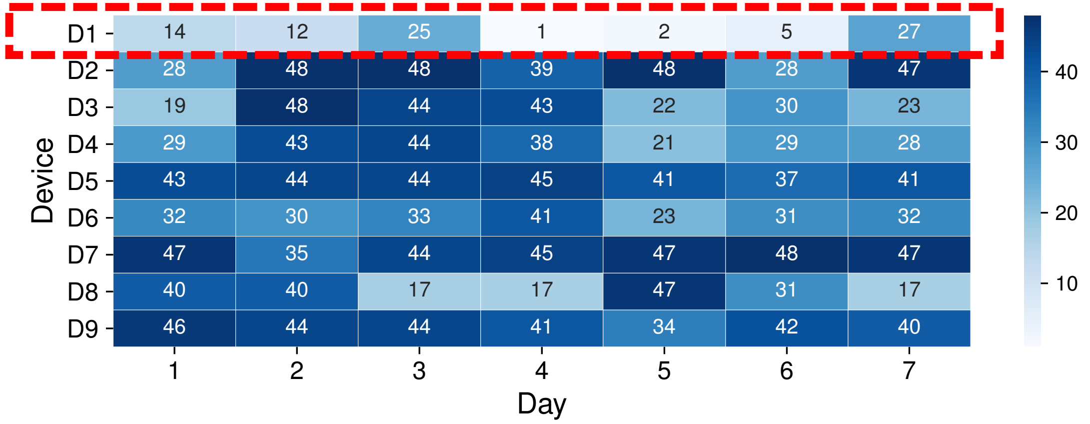
Weather

Responsed ESM and Received SPN

- **All participants** (excluding D1) had response to a survey (open the app) more than 2 times/day.
- **D1** received a smaller number of SPNs (12.29 times/day) than other devices



Number of Responsed ESM

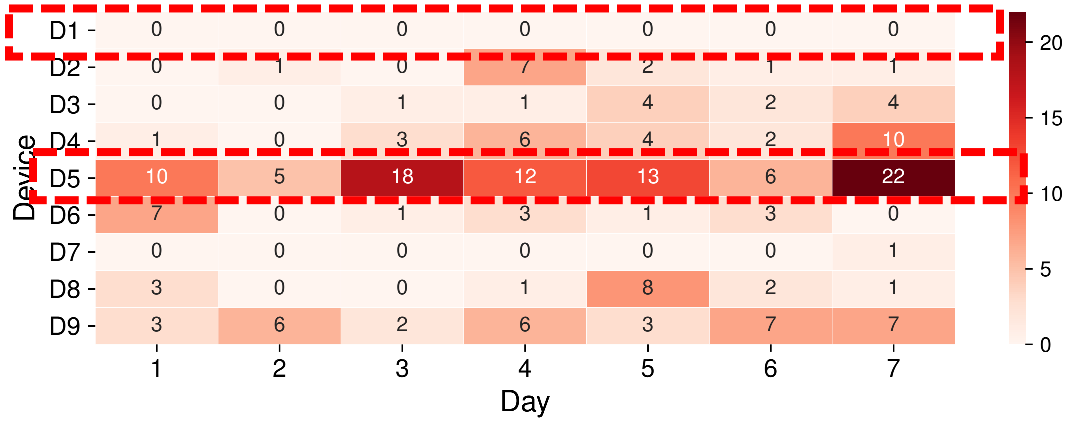


Number of Recived SPNs

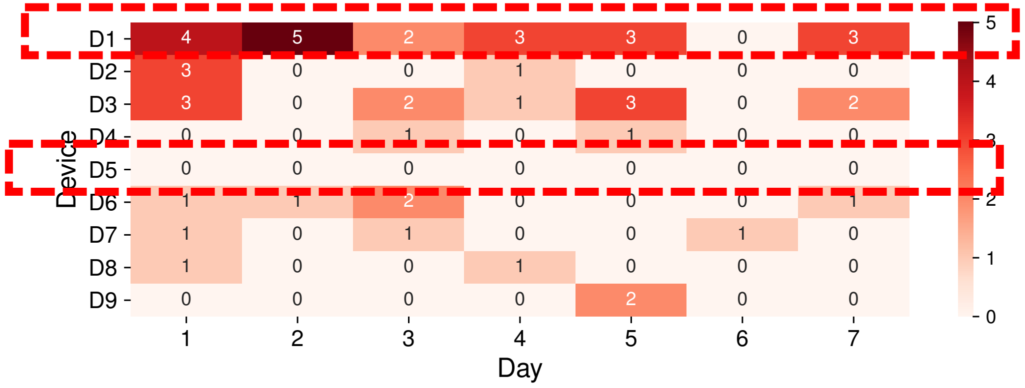
Memory Warning and Terminate Events

- **D5** has recevided much memory warnings during this study (12.29 times in a day)

- **D1** terminates the app frequently than other devices (2.86 times in a day)
- **D5** did not terminate the app during the study



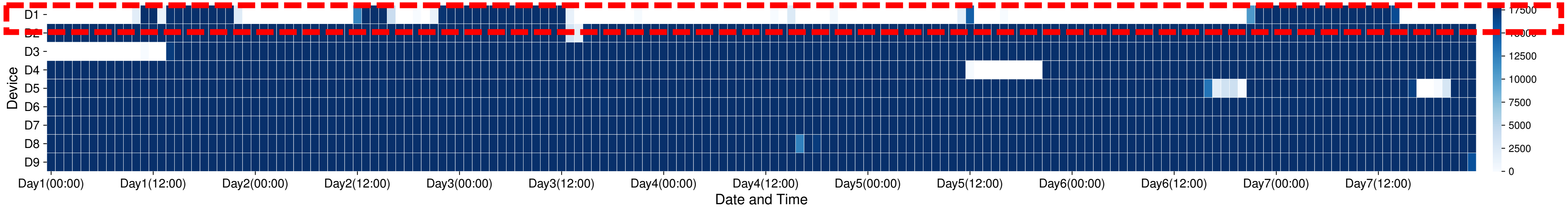
Memory Warnings



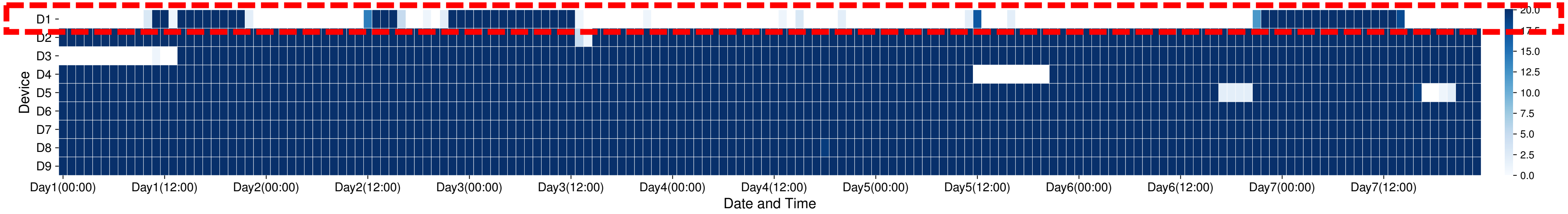
Terminate Events

Data Collection by Every Hour:
Location, Accelerometer, and Weather Sensor

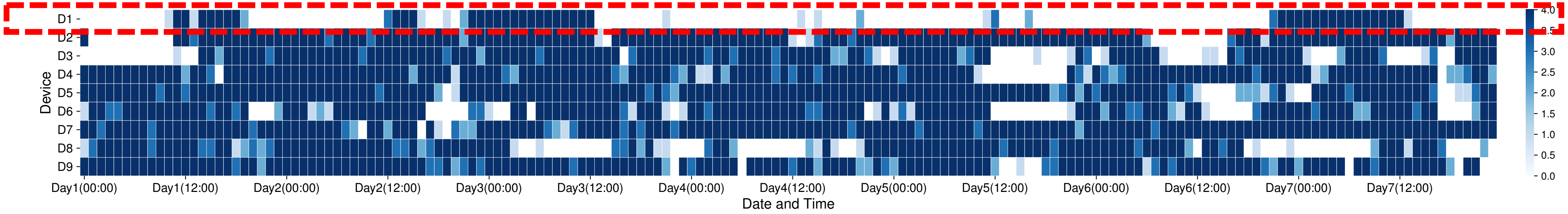
Location



Accelerometer

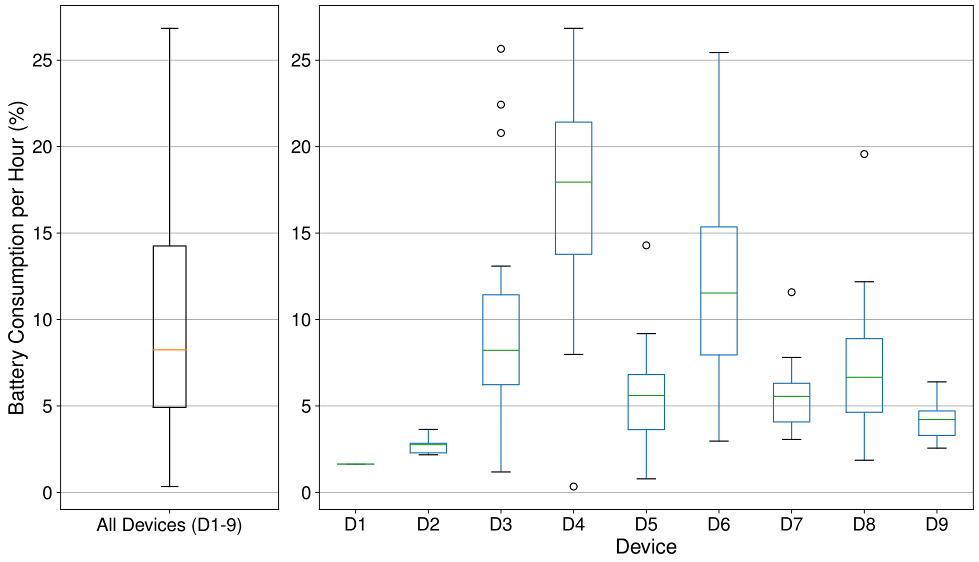


Weather



Battery Consumption

- Median of battery consumption per hour is 8.24% (N:166, Mean: 10.1, SD:6.65)
- Excluding D1, D2 does not consume battery (2.76% per hour), but D4 consumed 17.95% per hour.



Battery Consumption

- Participants tend to feel the battery consumption is slightly high but seems to be not a significant effect on their smartphone usage in their daily life

Result of Questionnaire

#	Question	1	2	3	4	5	6	7	Mode
Q1	How did you perceive the battery life of your smartphone during this study when compared to normal use? 1:Very impacted – 7:No impact at all	1	3	4	0	1	1	0	3
Q2	How much did you feel the battery life has restricted your daily activity? 1:Very restricted – 7:Not restricted at all	1	0	3	0	2	2	2	3
Q3	How did you feel regarding the frequency of ESMs? 1:Too much frequent – 7: Not frequent at all	0	1	4	2	2	0	1	3

Disucssion

Data collection Rate

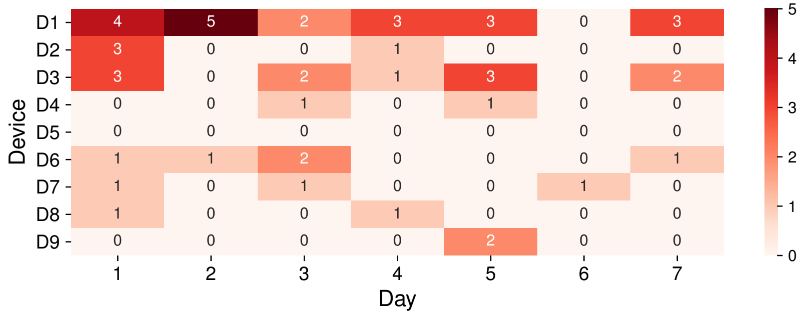
- More than "95% of data from hardware sensors" and "80% of data from RESTful API" can collect unless a user terminates the app by using the ESM+SPN condition

Potential risks of data collection

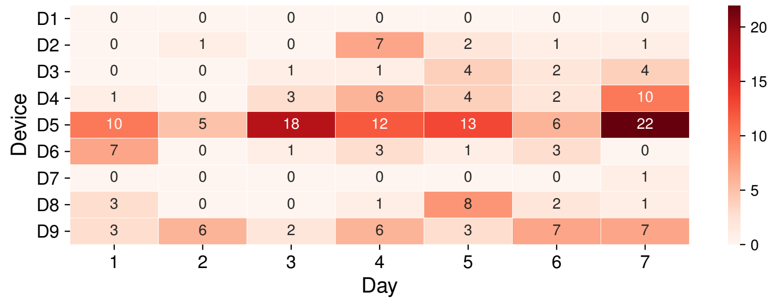
- App terminations reduce the quality of data collection
- Wemory warnings does not make significant effect in the ESM+SPN condition
- Free storage size is a potential risk (D1, 2, and 9)

Battery life and user’s feeling

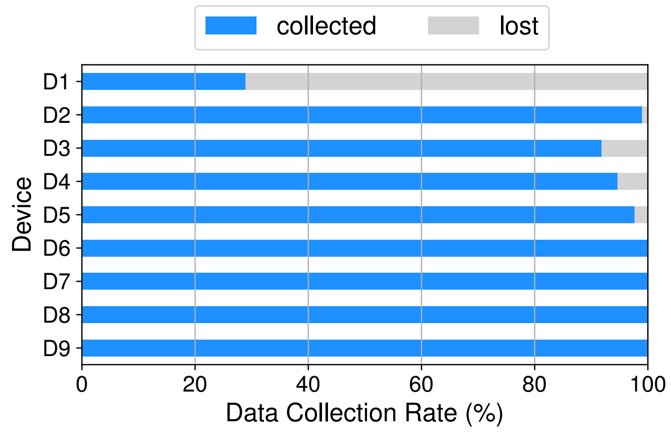
- Battery consumption is completery different between users (min. case: 2.76 per hour vs. max. case: 17.95 per hour)
- Participants does not feel significant effect on their smartphone usage in their daily life by using this tool



Terminate Events



Memory Warnings



Location Sensor

Future Works

- Evaluations in the other cases:
  - Baseline, ESM, and SPN condition
  - The performance in the long-term study
  - Combination of sensor and OS
- Automatic performance assessment and report function in the wild condition

Conclusion

We assess the data collection quality of a MCS tool, installed on off-the-shelf iOS smartphones with ***9 participants for a week in-the-wild condition + ESM+SPN condition***.

More than **97% of sensor data, provided by hardware sensors** (i.e., accelerometer, location, and pedometer sensor), **is successfully collected in the wild condition, *unless a user explicitly quits our data collection application.***

Thank you for your attention.

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yuukin@iis.u-tokyo.ac.jp