Field Lab Sleep and Energy: A System for Longitudinal Remote Sleep Tracking and Prototyping

Peter Lovei Eva Deckers peter.lovei@philips.com eva.deckers@philips.com Philips Experience Design Eindhoven, The Netherlands Mathias Funk Stephan Wensveen m.funk@tue.nl s.a.g.wensveen@tue.nl Industrial Design, Eindhoven University of Technology Eindhoven, The Netherlands



Figure 1: The Field Lab Intelligent ecosystem illustrated by a participant looking at the Field Lab Sleep mobile application (left), and two data visuals that are based on data collected by the shown Wakeup Light [9] and the Withings Sleep Analyzer [15] (right)

ABSTRACT

There is both clinical and consumer interest in remote sleep tracking technologies. Sleep is interesting to be observed remotely, in a (smart) home environment. For longitudinal design research we needed to collect data for a longer period of time. Therefore, using the Data-Enabled Design process we built Field Lab Sleep and Energy. We conducted a user study for a period of one year using this system. Using the system the team could gather, store, process, visualize and analyze the incoming behavioral, experiential and contextual data. We built and embedded a communication platform in the system aiming to prototype human-IoT experiences. The RelaxBreathe program was one of these prototyped and tested human-IoT experiences. This positioning paper introduces Field Lab Sleep and Energy, the RelaxBreathe program case study and the findings of the team.

CCS CONCEPTS

• Human-centered computing \rightarrow Systems and tools for interaction design; User studies.

KEYWORDS

data-enabled design, longitudinal design research, human-IoT experiences, prototyping, designing for sleep

1 INTRODUCTION

There is both clinical and consumer interest in remote sleep tracking using wearable technologies [10]. Sleep is complex and both objective and subjective, Sleep is personal and context dependent. Sleep varies over time. As such it is a suitable topic to be explored by remotely tracking it at people's homes. Liang et al.'s [7] paper describes SleepExplorer a visualization tool for personal sleep data and contextual factors. Their sleep study was conducted for two weeks in length. The authors emphasize the opportunity for being able to provide tailored instructions and recommendations for behavior change. In order to do so a longer period of data collection is necessary.

Copyright 2021 for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

CHIIoT 1, February 17, 2021, Delft, The Netherlands

By applying the Data-enabled Design (DED) process [13] it is possible to design prototypes for intelligent ecosystems. Using these prototypes a multidisciplinary design (research) team collects objective and subjective data [8]. The built systems consist of (IoT) products, services and people. The team is actively involved in setting up, conducting, analyzing and communicating the results of these studies. Studies in the past were conducted for a short to medium period of time (1-4 months). However, it is not always possible to learn enough about a certain domain, or about the everyday use of the designed intelligent ecosystem without deploying it in the field for a longer period of time. Therefore, we decided to explore how to conduct longitudinal design research for a period of a full year focusing on the topic of remote sleep tracking using IoT technologies. We built the Field Lab Sleep and Energy system. In this positioning paper we are presenting a case study about how to prototype Human-IoT experiences using Field Lab Sleep and Energy.

2 FIELD LAB SLEEP AND ENERGY

Field Lab Sleep and Energy is an intelligent ecosystem designed for conducting longitudinal design research, exploring the topic of remote sleep tracking using IoT technologies deployed in people's home environment. By applying the DED process [13] the design research team has made the following decisions for the design of the system. Field Lab Sleep and Energy consists of off-the shelf IoT devices that collect contextual, behavioral and experiential data related to remote sleep tracking and can be used in the home environment of its users. The built system is made to function for a duration of a full year.

Using the system the team wanted to be able to prototype human-IoT experiences based on the data collected via the remote sleep tracking activities. Therefore, we developed a way to be able to gather, store, process, visualize and analyze the incoming data. Moreover, by building and embedding a communication platform in the Field Lab Sleep and Energy system the design research team could (1) instruct participants, (2) modify the functionality of the design probes, and (3) gather feedback about how the participants are experiencing the ecosystem they're using.

2.1 Conducted User Study

From December 2018 till December 2019 we conducted the Field Lab Sleep and Energy study. We deployed the Field Lab system in the homes of five participating families from the Eindhoven region of The Netherlands. The five participating couples were selected to be (1) healthy individuals with no (diagnosed) sleep disorder, and (2) tech savvy consumers. During the study we collected 2979 nights of Withings data, 876 days of subjective sleep data, 109076 data points about their bedroom environment, the participants opened the app 4500 times, and 10350 Chat messages were exchanged via the built communication platform. The study was positively approved to be conducted by the Internal Committee for Biomedical Experiments (ICBE) of Philips. Lovei, et al.



Figure 2: The Field Lab system consisting of (1) a Withings Sleep Analyzer [15], (2) a Somneo Wakeup Light [9], and (3) the Field Lab Sleep mobile application used as a communication platform. The arrows show the possibility of interaction between the participants and the design probes.

2.2 Remote data collection via the Field Lab system

Using the Field Lab system we can collect behavioral, experiential and contextual data. It is achieved by the deployment of the following design probes at participating families' homes: (1) Withings Sleep Analyzer [15], (2) a Somneo Wakeup Light [9], and (3) the Field Lab Sleep iOS application.

2.2.1 Withings Sleep analyzer. The Withings Sleep Analyzer is a WiFi-enabled IoT device that is placed under the mattress in the bed. The device collects data about its users' sleep and sends the collected data over WiFi to the Withings cloud. The Field Lab Sleep and Energy system is able to retrieve the collected, and analyzed sleep data from the Withings cloud via their official API [14].

Data collected by Withings Sleep Analyzer that is used by Field Lab:

- Time participant spends in bed (duration)
- Total sleep time (duration)
- Time awake (duration)
- Sleep efficiency (percentage: time asleep / total duration in bed)
- Sleep onset (timestamp)
- Sleep offset (timestamp)

2.2.2 Somneo Wakeup Light. The Somneo Wakeup Light is a WiFienabled IoT device that uses light and sound to wake its users up. It is possible to setup the alarm time and customize its sound via the display of the light or via a smartphone application. There is a relaxed breathing feature (RelaxBreathe) offered by the light as well. This feature can be triggered manually via the display of the light. The light contains sensors that collect data about the bedroom environment of the user.

Data collected by Somneo Wakeup Light that is used by Field Lab:

- Temperature (degrees)
- Humidity (percentage)
- Sound level (decibel)
- Light level (lux)
- Time RelaxBreathe feature was started (timestamps)
- Time RelaxBreathe feature was ended (timestamps)
- Alarm usage (timestamps)

2.2.3 Field Lab Sleep mobile application. The Field Lab Sleep mobile application was custom-developed for Field Lab. It was developed using React Native [11] for iOS devices. First of all we built a Chatbot to keep participants engaged during the study, ask questions for gathering feedback, and for being able to remotely instruct participants on how to use the devices. Secondly, we built a Newsfeed to provide content to keep participants engaged, and educate them about their sleep. Finally, we developed a way for participants to look at visualized data reports and feedback. The participants are encouraged to use the app on a daily basis and are notified every time there is a new chat message, Newsfeed content or personalized report sent to them.

Data collected by the Field Lab Sleep mobile application that is used by Field Lab:

- App usage data (opening, closing timestamps, duration spent on screens)
- Sleep related questions and answers: Sleep quality, Restfulness/Refreshed, Alertness, Consensus Sleep Diary [2]
- Qualitative questions and answers (scale from 1-10)



Figure 3: Data visual showing the temperature data collected by the Somneo Wakeup Light [9] (top), the sleep data collected by Withings Sleep Analyzer [15] (bottom), and the subjective sleep quality as reported on a scale from 1-10 (best score is 10) by the study participant (right)

2.3 Components built for prototyping Human-IoT experiences using the Field Lab Sleep and Energy system

Using the Field Lab system the team was able to create prototypes to (remotely) test Human-IoT experiences. This is achieved by using the following two components: (1) the back office and (2) the communication platform. During the study we used the system to modify the capabilities of the IoT components, tracked the usage of system components, instructed participants to use the devices differently, and gathered feedback about the experience of participants using the system via the mobile application. 2.3.1 The back office of the Field Lab Sleep and Energy system. In order to be able to analyze the incoming experiential, behavioral and contextual data we built a back office that could be centrally accessed by all the members of the (design) research team. The back office was deployed on AWS and data is stored in MongoDB. The main functionalities of the back office are the following: (1) present data visualisations to the researchers based on the collected data, (2) enable the researchers to play with the incoming data and the data visualizations.



Figure 4: The Field Lab system allows the remote checking and control of the the Somneo Wakeup Light

2.3.2 The communication platform of the Field Lab system. Using the communication platform of the Field Lab Sleep and Energy system the (design) research team can (1) schedule pre-written chat bot messages, and news feed articles, (2) compose reports about the participants data that can be shown in the Field Lab Sleep mobile application. The chat bot messages are pre-written in the Flow.AI [3] platform that is used to define the logic of the chat bot. The back office of the Field Lab communicates with Flow.AI via their WebSocket API [4]. The news feed articles are stored in a MongoDB database. The researchers need to define their title, subtitle, and a URL that points to the content to be shown to the participants. The reports about the participants' data are special kind of news feed articles that contain a link to a PDF document that is stored in an AWS S3 bucket.

3 CASE STUDY: RELAXBREATHE PROGRAM

The Field Lab Sleep and Energy system was created in order to prototype Human-IoT experiences. Based on the collected data from the Withings Sleep Analyzer and the answers given to the sleep related questions asked via the communication platform we noticed that 5 of the 10 participants had troubles falling at least twice a week. Therefore we decided to introduce the RelaxBreathe program, a personalized, visually-guided breathing program that can prevent stress to accumulate during the day, in order to facilitate sleep initiation and continuation at night.

In order to prototype this experience the team has used the back office, the communication platform and the Somneo Wakeup Light. We developed a custom solution that uses a Raspberry Pi [6] with Node-RED [5] installed on it to connect to the Somneo Wakeup light via the local WiFi network. This way it is possible to read out sensor data from the light and control the Relax Breathe feature. It was achieved by sending AWS IoT [1] messages to the Raspberry Pi that triggers the commands on the Somneo by first finding the device on the local WiFi based on its' Mac address and then forwarding an HTTP POST command to the device over the local WiFi network. The device itself is able to interpret the incoming message and trigger the RelaxBreathe feature as if the participant pressed the respective button on its display.

Using the communication platform we sent chat messages to each participant of the study that they could read inside the Field Lab Sleep mobile application. By reading the messages they were introduced to the program, and we asked whether they were interested in joining it. If they decided they wanted to participate they were guided to setup their schedule. Depending on their schedule they received a Chat-based prompt together with a push notification to start the breathing exercises on their Somneo Wakeup Light. Each participant could decide to (1) use the light for the breathing exercises, (2) delay the exercise for a later moment, or (3) to skip the exercise. After they have finished with their exercise they got an encouraging message from the system. If the participants decided to do the breathing exercise the Flow.ai was programmed to ask the back office to send a message to the Raspberry Pi via the AWS IoT service to start the exercise over the local WiFi network to which the Somneo light was connected.

Next to the exercises we sent tips and news feed articles related to the benefits of the relaxation before going to bed. After 7 days the participants received a personal report that included a data visual and had the opportunity to reflect on the program. They could decide to (1) continue as before, (2) adopt their schedule, (3) or leave the program.

3.1 Results

Two of the 10 participants have decided to continue the program even though we have told them via the Chat messages that the program was over. They reported that the program helps them falling asleep better and helps them relaxing. We have also received feedback on how to improve this experience by further personalizing the program to the user's context. For one of the participants using the light felt like a task instead of relaxation as this person did not have problems with falling asleep. Other users have reported to make the time of the exercise more easily customizable, as many times it happened that the exact moment they received the Chat prompt they were doing something else and then forgot about it. Moreover, the participants have also provided feedback for how to improve the IoT aspect of the program as they have asked us to introduce different channels or devices for delivering the exercise. One participant would have preferred voice based guidance instead of the light based one provided by our team. Last but not least, our

program has also shown the importance of improving the Field Lab Sleep and Energy system to gather data about people's motivation when testing out human-IoT experiences. Based on the suggestions of the users the program could be improved by further improving the connection to all the experiential, contextual, and behavioral data that was collected from their homes.

4 CONCLUSION AND FUTURE WORK

In this position paper we presented Field Lab Sleep and Energy. The system was designed for longitudinal design research into remote sleep tracking. The introduced system was used in a design research study for the duration of one year. We selected the IoT components that were deployed in people's homes in a way that based on the gathered, and analyzed remote sleep tracking data the team could come up and prototype new human-IoT experiences. By developing and embedding a communication platform the design research team was able to instruct participants to use the devices differently, track their device usage and gather their feedback about the new way of using the IoT device. This way we could prototype a new human-IoT experience.

The presented case study shows how to remotely setup a relaxation before sleep experience. The case study was successful for setting up and executing the program, and gathering feedback from the participants. Some participants have appreciated using it while others have provided valuable feedback to further improve the experience and the Field Lab Sleep and Energy system.

During the one year the system was used for prototyping other experiences around the topic of family sleep [12], bedroom environment and sleep regularity. In all cases we used the same method of instructing participants, potentially modifying the technical setup, tracking the usage interactions and gathering feedback using the system. In the future we aim to explore other health technology topics using similar ecosystems that are designed by applying the DED process.

ACKNOWLEDGMENTS

The authors would like to thank Anne Wil Burghoorn, Melanie Meyfroyt, Erwin Hoogerwoord, Thomas Visser and the rest of the colleagues working on this project. We also would like to thank the participants of the Field Lab Sleep and Energy study.

REFERENCES

- [1] Amazon. 2020 (accessed January 4, 2021). AWS IoT. https://aws.amazon.com/iot/
- [2] Colleen E Carney, Daniel J Buysse, Sonia Ancoli-Israel, Jack D Edinger, Andrew D Krystal, Kenneth L Lichstein, and Charles M Morin. 2012. The consensus sleep diary: standardizing prospective sleep self-monitoring. Sleep 35, 2 (2012), 287–
- 302.[3] Flow.ai. 2020 (accessed January 4, 2021). Flow.ai. https://flow.ai
- [4] Flow.ai. 2020 (accessed January 4, 2021). Flow.ai Socket API. https://flow.ai/docs/ api-docs/#socket-api
- [5] OpenJS Foundation. 2020 (accessed January 4, 2021). Node-RED. https://nodered. org
- [6] Raspberry Pi Foundation. 2020 (accessed January 4, 2021). Raspberry Pi. https: //www.raspberrypi.org/products/raspberry-pi-3-model-b/
- [7] Zilu Liang, Bernd Ploderer, Wanyu Liu, Yukiko Nagata, James Bailey, Lars Kulik, and Yuxuan Li. 2016. SleepExplorer: a visualization tool to make sense of correlations between personal sleep data and contextual factors. *Personal and Ubiquitous Computing* 20, 6 (2016), 985–1000.
- [8] Peter Lovei, Eva Deckers, Mathias Funk, and Stephan Wensveen. 2020. The Marios and Luigis of Design: Design Plumbers Wanted!. In Companion Publication of the 2020 ACM Designing Interactive Systems Conference. 197–201.

Field Lab Sleep and Energy: A System for Longitudinal Remote Sleep Tracking and Prototyping

 [9] Philips. 2019 (accessed March 10, 2020). SmartSleep Connected Sleep and Wakeup Light. https://www.usa.philips.com/c-e/smartsleep/connected-sleepand-wakeup-light.html Vol. 29. WILEY 111 RIVER ST, HOBOKEN 07030-5774, NJ USA, 231-232.

- [13] Janne van Kollenburg and Sander Bogers. 2019. Data-enabled design: a situated design approach that uses data as creative material when designing for intelligent ecosystems. Ph.D. Dissertation.
- [10] Anita Valanju Shelgikar, Patricia F Anderson, and Marc R Stephens. 2016. Sleep tracking, wearable technology, and opportunities for research and clinical care. *Chest* 150, 3 (2016), 732–743.
- [11] Facebook Open Source. 2020 (accessed January 4, 2021). React Native. https: //reactnative.dev
- [12] T Vacaretu, S Pillen, AW Burghoorn, M Knufinke, P Lovei, S Overeem, C. van derzwaluw, T Visser, and P Markopoulos. 2020. How did you sleep? Exploring byproxy sleep assessment in a field study setup. In *JOURNAL OF SLEEP RESEARCH*,
- [14] Withings. 2020 (accessed January 4, 2021). Withings Developer Documentation. https://developer.withings.com/oauth2/
- [15] Withings. 2020 (accessed January 4, 2021). Withings Sleep Analyzer. https: //www.withings.com/nl/en/sleep-analyzer