

DRAFT 2020-06-08

The latest version is available at [erik.bjareholt.com/thesis/goaldocument.pdf](http://erik.bjareholt.com/thesis/goaldocument.pdf)

M.Sc. Thesis proposal

# Classifying brain activity using low-cost biosensors and automated time tracking

Erik Bjäreholt

(erik@bjareho.lt, dat13ebj@student.lu.se)

Student Erik Bjäreholt  
 Supervisor Markus Borg  
 Examiner Elizabeth Bjarnarson  
 Start date 10th June (realistic?)  
 End date 30th September (realistic?)

## I. BACKGROUND

People spend more time than ever using computing devices. Work, entertainment, and services, have been steadily moving online over the last few decades and this trend is expected to continue. While several studies have been tracking how people spend time on their devices a wider study of how people's app usage is changing over time and how it varies with demographics, is not publicly available.

Furthermore, how different device activities affect the user behaviorally and neurologically is of interest for many areas of research, including:

- psychological well-being, such as depression and social anxiety [1][2], stress [3], self-esteem, life satisfaction, loneliness, and depression [4].
- the impact of screen time on children and adolescents [5].
- attention span among media multitasking adults [3].
- enhancing personal productivity [6].

Understanding device use and the underlying cognitive processes are essential when designing for motivation, engagement and wellbeing in digital experiences [7].

## CONTENTS

<b>I</b>	<b>Background</b>	1
I-A	Automated time trackers . . . . .	1
I-A1	Commercial use . . . . .	1
I-A2	Research use . . . . .	2
I-A3	ActivityWatch . . . . .	2
I-B	Low-cost functional brain imaging . . . . .	2
<b>II</b>	<b>Problem description, research goals and questions</b>	2
II-A	Goals . . . . .	2
II-B	Questions . . . . .	2
II-C	Challenges . . . . .	2
<b>III</b>	<b>Methodology</b>	3
<b>IV</b>	<b>Scientific contributions</b>	3
<b>V</b>	<b>Resources</b>	3

## NOTES & TODOS

<input type="checkbox"/>	<b>Add:</b> Paragraph leading into the CNN classifier part	2
<input type="checkbox"/>	<b>Add:</b> Summary of EEG datasets/challenges on Kaggle	2
<input type="checkbox"/>	<b>Add:</b> Goals . . . . .	2
<input type="checkbox"/>	<b>Add:</b> More challenges . . . . .	3
<input type="checkbox"/>	<b>Unsure:</b> Maybe out-of-scope, but obvious synergies so might not be extra work. . . . .	3
<input type="checkbox"/>	<b>Unsure:</b> Will it be of use? . . . . .	3
<input type="checkbox"/>	<b>Unsure:</b> Maybe just a single subject for simplicity . . . . .	3

### A. Automated time trackers

Automated time-trackers have been developed for computing devices for various applications such as tracking productivity, managing excessive use of social networking sites (SNSs).

1) *Commercial use:* Companies like RescueTime [8], Hubstaff [9], and others offer automated time tracking as a service. These services let the user track their screen time by installing a program on their device which tracks the active application and sends the data to their servers for storage and analysis. The user can then view their data in a dashboard on the service's website. Some of these services, like RescueTime and Hubstaff, are marketed towards teams and professionals, who want to keep track of individual and team productivity.

However, these services have some issues for use by researchers and individuals alike. Notably, their collection of detailed and non-anonymized behavioral data into a centralized system bring significant privacy concerns, especially in cases where the data is shared with a team or an employer.

Other limitations of these services, such as low temporal resolution and limited event detail, cause additional issues for certain tasks that are timing-sensitive (such as ERPs), or preprocessing steps that can take advantage of high level of detail (like classifying activity).

2) *Research use*: Previous research has been published which used automated time trackers, such as TimeAware [6] and ScreenLife [10]. However, these previous contributions are — like the commercial services — not open source or permissively licensed and therefore not available for external research use nor further development.

3) *ActivityWatch*: The free and open source automated time tracker ActivityWatch [11] addresses aforementioned issues with other software around source availability/licensing, privacy, temporal resolution, event detail, and cross-platform support.

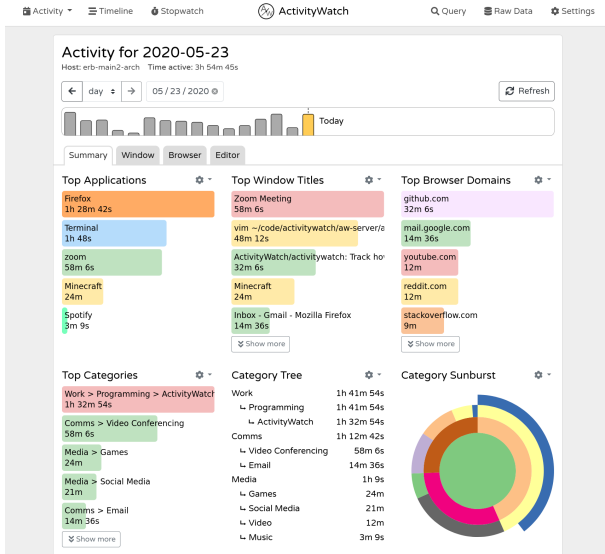


Fig. 1. ActivityWatch activity dashboard. Showing top applications, window titles, browser domains, and categories.

## B. Low-cost functional brain imaging

Functional brain imaging methods such as fMRI, fNIRS, and EEG, have been used to study the relationship between cognitive or physical activity, and brain activity [12][13][14]. The more accurate methods such as fMRI are costly and inflexible/impractical for many uses.

However, the recent availability of low-cost biosensors such as EEG, HEG, and fNIRS, enables studying brain activity during real-life tasks. As an example it has been shown that it is

possible to classify what task a participant is undertaking using fMRI [12], which has been replicated using EEG and low-cost biosensors [14].

But they are not without their limitations — among them a notably low signal-to-noise ratio [15] — yet visual evoked potentials (VEPs) have been shown to be sufficient for high-speed BCI applications [16].

Add: Paragraph leading into the CNN classifier part

Convolutional Neural Networks (CNNs) have been successful in classifying time series in general [17], and EEG data in particular [18]. Additionally, Hierarchical Convolutional Neural Networks (HCNNs) have been used for EEG-based emotion recognition [19].

Add: Summary of EEG datasets/challenges on Kaggle

## II. PROBLEM DESCRIPTION, RESEARCH GOALS AND QUESTIONS

The aim of this project is to investigate whether EEG and other low-cost biosensors can be used to accurately classify device activity in a broader context than previous studies. This will be useful to future BCI applications where a command might be specific to a particular context.

EEG and other low-cost biosensors have been successful in capturing emotional states. Thus combined tracking of device activity and emotional state can be used to see study associations between emotional state and device activity.

### A. Goals

Add: Goals

### B. Questions

Can low-cost biosensors, like EEG, be used to...

- Classify which device activity the user is engaging in?
- Track emotional states during device use?
- Measure focus/distractibility?
- Predict context switching?

### C. Challenges

- Low volume of EEG data collected (limited time for data collection)
- Limitations of low-cost EEG equipment (small number of channels)
- Orthogonal stimuli (eye movement/blinking, use of keyboard/mouse) which will contribute significant noise to the EEG readings not relevant for the classification task.

- Scope creep (hopefully resolved by the time this document is finalized)

Add: More challenges

### III. METHODOLOGY

We will collect EEG data from subjects during normal device use. Device activity will be recorded and categorized with ActivityWatch. The categorization will be used to train an EEG classifier on device activity.

### IV. SCIENTIFIC CONTRIBUTIONS

- A EEG classifier for device activity.
- Relationships found between device activity and brain activity, as measured by EEG.
- An example for how to use the open-source automated time tracker ActivityWatch in research.
- The addition of EEG-derived data to ActivityWatch.

### V. RESOURCES

- OpenBCI Cyton biosensing board (8 channel) and Ultra-cortex headset
- HEGduino
- Test subjects

### REFERENCES

- [1] Maarten H. W. Selfhout et al. "Different types of Internet use, depression, and social anxiety: The role of perceived friendship quality". In: *Journal of Adolescence* 32.4 (Aug. 1, 2009), pp. 819–833. ISSN: 0140-1971. DOI: [10.1016/j.adolescence.2008.10.011](https://doi.org/10.1016/j.adolescence.2008.10.011). URL: <http://www.sciencedirect.com/science/article/pii/S0140197108001218> (visited on 05/13/2020).
- [2] Dhavan Shah et al. "Nonrecursive Models of Internet Use and Community Engagement: Questioning Whether Time Spent Online Erodes Social Capital". In: *Journalism & Mass Communication Quarterly* 79.4 (Dec. 1, 2002). Publisher: SAGE Publications Inc, pp. 964–987. ISSN: 1077-6990. DOI: [10.1177/107769900207900412](https://doi.org/10.1177/107769900207900412). URL: <https://doi.org/10.1177/107769900207900412> (visited on 05/13/2020).
- [3] Gloria Mark, Yiran Wang, and Melissa Niiya. "Stress and multitasking in everyday college life: an empirical study of online activity". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '14. Toronto, Ontario, Canada: Association for Computing Machinery, Apr. 26, 2014, pp. 41–50. ISBN: 978-1-4503-2473-1. DOI: [10.1145/2556288.2557361](https://doi.org/10.1145/2556288.2557361). URL: <https://doi.org/10.1145/2556288.2557361> (visited on 05/22/2020).
- [4] Chiungjung Huang. "Time Spent on Social Network Sites and Psychological Well-Being: A Meta-Analysis". In: *Cyberpsychology, Behavior, and Social Networking* 20.6 (June 1, 2017). Publisher: Mary Ann Liebert, Inc., publishers, pp. 346–354. ISSN: 2152-2715. DOI: [10.1089/cyber.2016.0758](https://doi.org/10.1089/cyber.2016.0758). URL: <https://www.liebertpub.com/doi/10.1089/cyber.2016.0758> (visited on 05/13/2020).
- [5] Kaveri Subrahmanyam et al. "The impact of computer use on children's and adolescents' development". In: *Journal of Applied Developmental Psychology*. Children in the Digital Age 22.1 (Jan. 1, 2001), pp. 7–30. ISSN: 0193-3973. DOI: [10.1016/S0193-3973\(00\)00063-0](https://doi.org/10.1016/S0193-3973(00)00063-0). URL: <http://www.sciencedirect.com/science/article/pii/S0193397300000630> (visited on 05/13/2020).
- [6] Young-Ho Kim et al. "TimeAware: Leveraging Framing Effects to Enhance Personal Productivity". In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. CHI '16. San Jose, California, USA: Association for Computing Machinery, May 7, 2016, pp. 272–283. ISBN: 978-1-4503-3362-7. DOI: [10.1145/2858036.2858428](https://doi.org/10.1145/2858036.2858428). URL: <https://doi.org/10.1145/2858036.2858428> (visited on 05/13/2020).
- [7] Dorian Peters, Rafael A. Calvo, and Richard M. Ryan. "Designing for Motivation, Engagement and Wellbeing in Digital Experience". In: *Frontiers in Psychology* 9 (2018). Publisher: Frontiers. ISSN: 1664-1078. DOI: [10.3389/fpsyg.2018.00797](https://doi.org/10.3389/fpsyg.2018.00797). URL: <https://www.frontiersin.org/articles/10.3389/fpsyg.2018.00797/full?report=reader> (visited on 05/23/2020).
- [8] *RescueTime: Automatic Time-Tracking Software*. Library Catalog: [www.rescuetime.com](http://www.rescuetime.com). URL: <https://www.rescuetime.com/> (visited on 05/23/2020).
- [9] *Hubstaff: Time Tracking and Productivity Monitoring Tool*. Library Catalog: [hubstaff.com](http://hubstaff.com). URL: <https://hubstaff.com/> (visited on 05/23/2020).
- [10] John Rooksby et al. "Personal Tracking of Screen Time on Digital Devices". In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. CHI '16. San Jose, California, USA: Association for Computing Machinery, May 7, 2016, pp. 284–296. ISBN: 978-1-4503-3362-7. DOI: [10.1145/2858036.2858055](https://doi.org/10.1145/2858036.2858055). URL: <https://doi.org/10.1145/2858036.2858055> (visited on 05/13/2020).
- [11] *ActivityWatch: Open-source automated time tracker*. In collab. with Erik Bjäreholt and Johan Bjäreholt. URL: <https://activitywatch.net/> (visited on 05/23/2020).
- [12] Benjamin Floyd, Tyler Santander, and Westley Weimer. "Decoding the Representation of Code in the Brain: An fMRI Study of Code Review and Expertise". In: *2017 IEEE/ACM 39th International Conference on Software Engineering (ICSE)*. 2017 IEEE/ACM 39th International Conference on Software Engineering (ICSE). ISSN: 1558-1225. May 2017, pp. 175–186. DOI: [10.1109/ICSE.2017.24](https://doi.org/10.1109/ICSE.2017.24).
- [13] Keum-Shik Hong, Noman Naseer, and Yun-Hee Kim. "Classification of prefrontal and motor cortex signals for three-class fNIRS-BCI". In: *Neuroscience Letters*

Unsure: Maybe out-of-scope, but obvious synergies so might not be extra work.

Unsure: Will it be of use?

Unsure: Maybe just a single subject for simplicity

- 587 (Feb. 5, 2015), pp. 87–92. ISSN: 0304-3940. DOI: [10.1016/j.neulet.2014.12.029](https://doi.org/10.1016/j.neulet.2014.12.029). URL: <http://www.sciencedirect.com/science/article/pii/S0304394014009744> (visited on 05/22/2020).
- [14] Davide Fucci et al. “A Replication Study on Code Comprehension and Expertise using Lightweight Biometric Sensors”. In: *2019 IEEE/ACM 27th International Conference on Program Comprehension (ICPC)*. 2019 IEEE/ACM 27th International Conference on Program Comprehension (ICPC). ISSN: 2643-7171. May 2019, pp. 311–322. DOI: [10.1109/ICPC.2019.00050](https://doi.org/10.1109/ICPC.2019.00050).
- [15] D. J. McFarland and J. R. Wolpaw. “EEG-based brain–computer interfaces”. In: *Current Opinion in Biomedical Engineering*. Synthetic Biology and Biomedical Engineering / Neural Engineering 4 (Dec. 1, 2017), pp. 194–200. ISSN: 2468-4511. DOI: [10.1016/j.cobme.2017.11.004](https://doi.org/10.1016/j.cobme.2017.11.004). URL: <http://www.sciencedirect.com/science/article/pii/S246845111730082X> (visited on 05/13/2020).
- [16] Martin Spüler. “A high-speed brain-computer interface (BCI) using dry EEG electrodes”. In: *PLoS ONE* 12.2 (Feb. 22, 2017). ISSN: 1932-6203. DOI: [10.1371/journal.pone.0172400](https://doi.org/10.1371/journal.pone.0172400). URL: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5321409/> (visited on 05/13/2020).
- [17] Bendong Zhao et al. “Convolutional neural networks for time series classification”. In: *Journal of Systems Engineering and Electronics* 28.1 (Feb. 2017). Conference Name: Journal of Systems Engineering and Electronics, pp. 162–169. ISSN: 1004-4132. DOI: [10.21629/JSEE.2017.01.18](https://doi.org/10.21629/JSEE.2017.01.18).
- [18] Robin Tibor Schirrmeister et al. “Deep learning with convolutional neural networks for EEG decoding and visualization”. In: *Human Brain Mapping* 38.11 (2017). \_eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1002/hbm.23730>, pp. 5391–5420. ISSN: 1097-0193. DOI: [10.1002/hbm.23730](https://doi.org/10.1002/hbm.23730). URL: <https://onlinelibrary.wiley.com/doi/abs/10.1002/hbm.23730> (visited on 05/22/2020).
- [19] Jinpeng Li, Zhaoxiang Zhang, and Huiguang He. “Hierarchical Convolutional Neural Networks for EEG-Based Emotion Recognition”. In: *Cognitive Computation* 10.2 (Apr. 1, 2018), pp. 368–380. ISSN: 1866-9964. DOI: [10.1007/s12559-017-9533-x](https://doi.org/10.1007/s12559-017-9533-x). URL: <https://doi.org/10.1007/s12559-017-9533-x> (visited on 05/22/2020).
- Research and Behavioral Science* 31.1 (2014). \_eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1002/sres.2169>, pp. 102–114. ISSN: 1099-1743. DOI: [10.1002/sres.2169](https://doi.org/10.1002/sres.2169). URL: <https://onlinelibrary.wiley.com/doi/abs/10.1002/sres.2169> (visited on 05/13/2020).
- Yu Zhang et al. “Multi-kernel extreme learning machine for EEG classification in brain-computer interfaces”. In: *Expert Systems with Applications* 96 (Apr. 15, 2018), pp. 302–310. ISSN: 0957-4174. DOI: [10.1016/j.eswa.2017.12.015](https://doi.org/10.1016/j.eswa.2017.12.015). URL: <http://www.sciencedirect.com/science/article/pii/S0957417417308291> (visited on 05/13/2020).
- Ji Peng Koh. “Brain computer interface via EEG signals”. In: (2018). Accepted: 2018-04-23T02:21:24Z. URL: <https://dr.ntu.edu.sg/handle/10356/73955> (visited on 05/13/2020).
- Lamyaa Sadouk. “CNN Approaches for Time Series Classification”. In: *Time Series Analysis - Data, Methods, and Applications* (Nov. 5, 2018). Publisher: IntechOpen. DOI: [10.5772/intechopen.81170](https://doi.org/10.5772/intechopen.81170). URL: <https://www.intechopen.com/books/time-series-analysis-data-methods-and-applications/cnn-approaches-for-time-series-classification> (visited on 05/22/2020).
- Christian Mühl et al. “A survey of affective brain computer interfaces: principles, state-of-the-art, and challenges”. In: *Brain-Computer Interfaces* 1.2 (Apr. 3, 2014). Publisher: Taylor & Francis \_eprint: <https://doi.org/10.1080/2326263X.2014.912881>, pp. 66–84. ISSN: 2326-263X. DOI: [10.1080/2326263X.2014.912881](https://doi.org/10.1080/2326263X.2014.912881). URL: <https://doi.org/10.1080/2326263X.2014.912881> (visited on 05/22/2020).
- ActivityWatch: Open source automated time tracker*. In col-lab. with Erik Bjäreholt and Johan Bjäreholt. original-date: 2016-04-27T15:26:09Z. May 23, 2020. URL: <https://github.com/ActivityWatch/activitywatch> (visited on 05/23/2020).

#### FURTHER READING

- John Rooksby et al. “Personal tracking as lived informatics”. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI ’14. Toronto, Ontario, Canada: Association for Computing Machinery, Apr. 26, 2014, pp. 1163–1172. ISBN: 978-1-4503-2473-1. DOI: [10.1145/2556288.2557039](https://doi.org/10.1145/2556288.2557039). URL: <https://doi.org/10.1145/2556288.2557039> (visited on 05/13/2020).
- Tsung-Sheng Chang and Wei-Hung Hsiao. “Time Spent on Social Networking Sites: Understanding User Behavior and Social Capital”. In: *Systems*