The Wordometer 2.0 – Estimating the Number of Words You Read in Real Life using Commercial EOG Glasses

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Abstract
On the basis of the motivation to increase daily reading volumes, this paper introduces an implementation of "Wordometer 2.0," which counts the number of read words in a day. While word count estimation using eye tracking glasses or medical EOG (Electrooculography) sensors has been already proposed, our aim is to implement the idea on an affordable device to quantify readings in the whole day.
We utilize commercial EOG glasses designed for everyday use. Our method was evaluated with a dataset involving five readers with 11 % error rate with user-independent training.

Author Keywords
Eye movement; electrooculography; reading; quantified self

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
The relationship between cognitive benefits (e.g. vocabulary skills, academic scores) and reading habits, especially increased reading volumes is well-explored in the study of education and cognitive science [2]. As people can be motivated to be physically fit by monitoring step counts [5], we believe that counting the number of words they read can help them improve their daily reading volumes. In this pa-

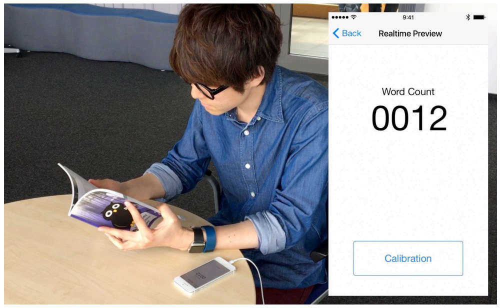

Figure 1: Overview of the application which counts the number of words a user read. He is wearing J!NS MEME.

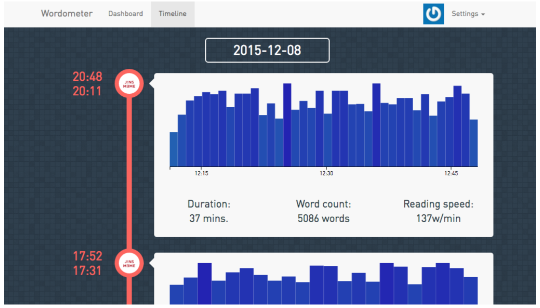

Figure 2: A screenshot image of the application to look back daily reading habits. The word counting application on iPhone sends the data to a web server, and it visualizes durations, word counts and the reading speeds of whole day.

per, we present the read word counting system which works on J!NS MEME, commercial EOG glasses (cf. Figure 1).

Quantifying reading activity is more difficult than tracking step counts because reading is not a physical activity, and it is hard to apply the same approach using body-mounted motion sensors. Additional sensors are needed to recognize reading activity. We employ an eye tracking approach to solve the problem. There is an array of research in psychology and cognitive science investigating the correlation between eye movements and cognitive activities including reading [6]. Furthermore, technologies for tracking eye movements are more and more pervasive these days [1].

The contribution of this paper is to show that (1) sensor signals from J!NS MEME are good enough to detect specific eye movements during reading (forward- and backward-saccades) and (2) the number of read words can be estimated by features from the forward- and backward-saccades. We have achieved an error rate of word counting algorithm 11% with user-independent training and 3.0% with user-dependent training. This research has been approved by the ethical committee of Osaka Prefecture University.

Wordometer 2.0

The idea of counting read words has been proposed by Kunze et al. as "Wordometer" [4]. They have introduced word counting algorithms based on mobile eye tracking glasses and medical EOG sensors. However, although their goal is to track daily reading habits, their setups are too bulky to be worn regularly (e.g., the devices are expensive; battery lives are not enough to cover a whole day; and cables on devices prevent a user from moving naturally).

Compared to the previous work, this research aims to quantify reading activities with technologies that are completely affordable. We utilize commercial EOG glasses because they are inexpensive, do not require significant user load, and have an long enough battery life for all-day use [3]. Additionally, there is no limitation to use the device from the viewpoint of privacy because it doesn't equip a camera. Features for the estimation are optimized for the device. We define our new word counting system which is designed for everyday use as "Wordometer 2.0."

Figure 3: The settings of electrodes to calculate EOG vertical and horizontal component on J!NS MEME.

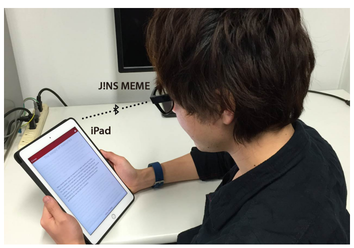

Figure 4: An overview of the experimental setup. Timestamps of start/stop reading paragraphs are recorded according to scroll events on iPad.

Owing to its advantages, the system can record natural reading activities during the whole day. Therefore, it enables a user to know and review his/her reading from a long-term view. The tracking result will be summarized and visualized as shown in Figure 2. Reading speeds can also be calculated by volumes in a period. By analyzing the rhythm of the reading speed, the system should be able to tell a user when the time to concentrate on reading was and in which part of a book did he/she was interested.

Word counting method

The word-counting method consists of three processes: obtaining a user's eye movements, detecting forward/backward-saccades, and estimating the number of words he/she read.

One reference electrode and two active electrodes are equipped on J!NS MEME as shown in Figure 3. The EOG vertical component is calculated as an average of L and R, and the horizontal component is calculated as the difference between L and R. Figure 5 shows an overview of the EOG horizontal component in a one-minute recording that includes reading activity. Negative values represent eye movement right to left, and positive values represent left to right. Regular patterns of eye movement appear during reading activity because of line breaks.

Figure 5 shows outputs of the algorithm of detecting forward- and backward-saccades. Peak detection for forward-saccades is applied after applying a median filter to remove noises. Backward-saccades are detected if the sensor value is lower than a threshold. The threshold is calculated dynamically as the difference between the mean and variance of sensor values in a small window. The window size is one second, which was decided experimentally.

The number of words a user read is estimated by support vector regression. Four features are calculated for the regression: the total number of forward-saccades, the mean EOG signal value of forward-saccades, the total number of backward-saccades, and the mean EOG signal value of backward-saccades.

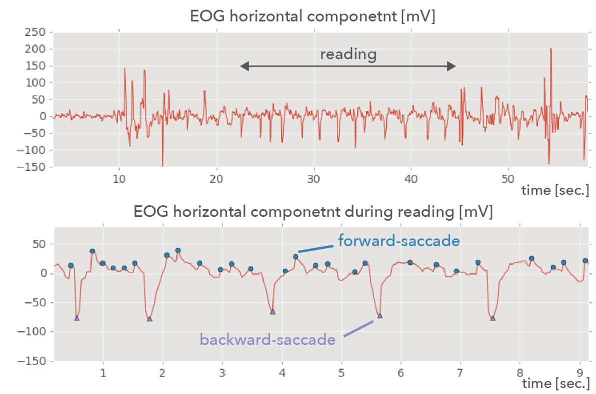

Figure 5: EOG sensor signal during reading activity. Circle and triangle markers are outputs of forward/backward-saccades detection.

Evaluation

To evaluate the word-counting algorithm, we asked five subjects to read English essays on an iPad wearing J!NS MEME (cf. Figure 4). Every subject read 38 paragraphs, so the total amount of paragraphs in the dataset was 190 (minimum: 27 words; maximum: 120 words; average: 60 words in one paragraph). Because we used a prototype device, the sampling frequency of the EOG signal was 11 Hz. Training and testing were done by leave-one-subject-out as a user-independent approach. We evaluated errors in the estimations with two measurements. One is an average of absolute error rates for each paragraph. This evaluation is valid for short-term recordings involving reading speed estimation. The other is an absolute error through

Table 1: Word count estimation errors

	user-independent		user-dependent	
Par.	each paragraph	all paragraph	each paragraph	all paragraph
a	17 %	11 %	14 %	2.2 %
b	24 %	9.5 %	25 %	6.4 %
c	24 %	18 %	15 %	2.4 %
d	15 %	7.5 %	15 %	1.8 %
e	15 %	11 %	12 %	2.4 %
Ave.	18 %	11 %	16 %	3.0 %

all paragraphs, which is calculated as the total error of all recordings. This evaluation is valid for long-term recordings including a total count of words read in a day.

The estimation errors are shown in Table 1. An average error of five subjects during the readings for each paragraph was 18% and decreased to 11% when extended with all 38 paragraphs. We also evaluated the algorithm with a user-dependent approach (10-fold cross-validation for each subject's data), and the average error was 16% for each paragraph and 3.0% through all paragraphs. The results represent the fact that eye movement during reading is user-dependent, and estimation errors will decrease by training with a user's behavior as he/she uses the system every day.

Conclusion and Future work

This paper described the word count estimating method and the summary visualization to increase daily reading volumes. The system works on commercial EOG glasses that are designed for everyday use. Future work includes recording long-term data in a realistic setup, and investigating effective feedbacks to improve a user's reading habits.

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