Collaborative Newspaper: Exploring an adaptive Scrolling Algorithm in a Multi-user Reading Scenario

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ABSTRACT
Digital content, like news presented on screens at public places (e.g., subway stations) is pervasive. Usually it is not possible for passers-by to conveniently interact with such public displays, as content is not interactive or responsive. Especially news screens are normally showing one news article after another, reducing the amount of information fitting the screen dimensions. In this paper we developed a collaborative newspaper application based on an adaptive scrolling algorithm, that manages scrolling of the same content for several users simultaneously. We are using head-mounted eye trackers to track people's gaze on the screen and detect their reading positions. Thus we offer the possibility to display news texts which are larger than the screen height, as the system automatically adapts the text scrolling to the person's reading behavior. In a user study with fifteen participants we investigated how the scrolling algorithm affects the reading speed of people in single- and multi-user scenarios. Further we evaluated the work load while using the system. The results show that the adaptive scrolling algorithm does not negatively influence the reading speed, neither in single- nor in a multi-user reading scenario.

Author Keywords
Collaborative; Multi-user reading; Adaptive scrolling; Gaze-based interaction; Shared content.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

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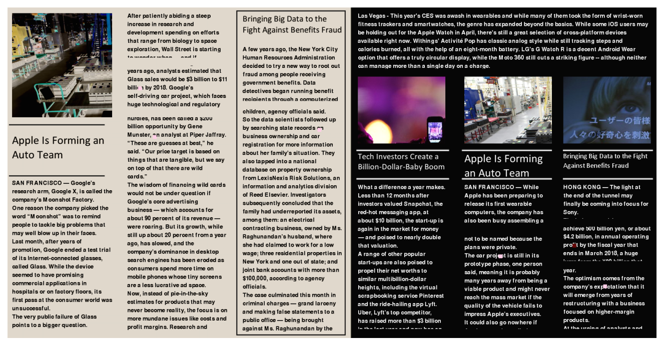

Figure 1. This figure illustrates the collaborative newspaper application with its three text columns, teaser image and article headlines. Left: day layout; Right: night layout.

INTRODUCTION
Over the last decade, the digital augmentation of urban space steadily increased. In addition to a tremendous number of smartphones and different kinds of sensors embedded into the urban environment, we can find more and more large scale displays (e.g., video walls and media facades) at public places. Gaze is a powerful modality to interact hands-free at a distance with the increasing number of public displays in our everyday environment. Gaze usually indicates what is attracting us and what might be interesting [13]. Gaze-based interaction is applied to various types of applications like desktop interaction [12] or eye typing [9]. The progress made over the last years in mobile eye tracking will advance the use of gaze-based interaction in our every day live [2].

When providing information like news, the main problem with large public displays is the lack of interactivity. Usually small abstracts of the daily headlines are presented to people in a round robin manner because many different information have to fit into the screen dimensions. Hence interested people have no possibility to receive further infromation about displayed content.

In this paper we present a collaborative newspaper system based on an adaptive scroll algorithm (see Figure 1). It provides the opportunity to display many news texts at once on a single screen. The news texts are shown in different columns and will be completely readable, even if they are not fitting the screen height. Head-mounted eye trackers are used to track persons' gaze on the screen and detect the location in the text to recognize their reading behavior. This knowledge is used to create personal view ports in which the scrolling speed is adapted to the individual reading speed. Furthermore our system enables people to simultaneously read the same text. In our prototypical implementation we allow up to three persons to read the same text simultaneously without distracting each other.

In a controlled laboratory experiment with 15 participants, we investigated if our adaptive reading algorithm affects the standard reading speed of people in single- and multi-user scenarios. In both conditions our system showed no negative effect on the reading speed, it actually slightly increased the performance of the participants.

RELATED WORK

The collaborative newspaper system comprises techniques and approaches from different domains. Specifically we identified (i) the characteristics of eye movements, (ii) techniques for gaze interaction, as well as (iii) interaction with public displays.

Eye Characteristics

Jacob [6] takes a closer look at eye characteristics and distinguishes between fixations where an eye focuses on a steady point and saccades, which are usually very quick and simultaneous eye movements.

In order to focus on a specific point or object (fixation), humans try to center it on the *fovea*, a small area in the center of the retina. However, the eye never stops moving completely, so even if the human thinks, he is looking steadily at one point, the eyes make very small movements, which are called *jittery motions*. Since the user is not aware of these, they can be ignored in applications. Another characteristic of eyes are *blinks*. As persons do not see anything during blinks, they can be neglected when designing applications [6].

A crucial problem is that not every fixation of the user's eyes means something. The user may just look around inspecting the graphical elements of the application or is absent-minded, which results in an interaction error. The user might then unintentionally trigger an event. This phenomenon is called Midas Touch, which is a common problem especially for undoable actions [6]. Finally, the determination of an appropriate dwell time is not trivial, because too short dwell times cause Midas Touches and too long fixations are inconvenient for humans [6]. In our work we mainly rely on gaze movements, ensuring that all allowed actions in our scenario are undoable.

Vrzakova et al. [14] present a taxonomy of interaction errors and remedial strategies users employ. They present nuances, richness and development of the user behavior when dealing with the outcomes of an error. We used their concept of automatic error-prevention mechanisms for gaze-based interaction in our scenario.

Gaze-based Interaction

In this paper, gaze interaction is performed using head-mounted eye trackers. They are very flexible as they allow the participants to move freely in front of the display, when a tracking algorithm is used to detect the display a person wants to interact with. However, they still require calibration to a stationary display [4].

In order to allow interaction with an application, it is necessary to declare eye gestures that trigger actions, e.g., dwell time [6]. If the user stares at a specific point for a certain time, e.g. 300 milliseconds, an action can be triggered. However, dwell time is not always the best suited eye gesture for all application scenarios. Instead it is also possible to identify even coarser gestures that are recognized over a longer period of time. Reading detection is a more complex gesture that is commonly known. In order to detect if a person is reading a text, her behavior (i.e. her alternations of fixations and saccades) has to be monitored for a certain amount of time. Moreover, it is possible to distinguish between discrete events, which are triggered once with a specific parameter and continuous events. Examples for discrete events are fixation recognition and reading detection, which is also part of the class of continuous events. Penkar et al. [11] developed and evaluated a method to recognize when users are reading text based on eye-movement data. Campbell et al. [3] defined three different distance categories for saccades (short, medium and large). Furthermore, they use special tokens for saccades depending on their distance and main direction (left, right, up or down). For the measurement of the distances in our approach, we compute the pixel distance for the main direction between the gaze position at the beginning and the end of a predefined period of time.

We further used the Pooled Evidence technique to reduce the influence of jitter, noise, regressions and movements above and below the current line. To implement this technique, an integer value and a reset flag are assigned to each token. If a token is recognized, its integer value will be added to the pool or it is reset to zero if the token carries the reset flag. As soon as the pool reaches a certain threshold, reading is detected until a token with a reset flag is identified [3].

Kumar et al. [8] proposes different approaches to control scrolling via gaze data in a single user setting. We use their findings and adapt one of their approaches to our needs. They further executed a pilot study where they found out that the participants could read comfortably although the text was moving. Their results show that our application may eventually become relevant in real life scenarios and has a good chance to be accepted by a broader public.

We choose the so called Eye-in-the-middle approach because it seemed to be most suitable for text-only content, which we use in our newspaper application. Based on this approach we developed an algorithm for smooth individual scrolling of text in a very small scroll view as a preparation for the multi-user scrolling algorithm.

Text 2.0 by Biedert et al. [1] uses a stationary eye tracker to support a person in a single user scenario reading a text on a normal desktop monitor. The system is able to detect the reading position and supports the user while reading with additional features (e.g., music adapted to the text, translation).

However, as it uses a remote eye tracking system it is not suitable for a multi-user scenario.

Public Displays

Considering technical aspects with regard to gaze-based interaction, it is also important to cope with special characteristics of applications running on large public screens. First of all it is essential to catch the attention of passers-by who do not initially want to interact. Müller et al. [10] states that a person's attention tends to be attracted by motion and moving objects are more likely to be noticed by humans. The so called honey-pot effect is an important factor, especially in the multi-user scenario of our work. It proposes that a display will be much more attractive, and thus more attended, if other people are already around the display. When the application has caught the attention of potential users, the next crucial step is to make them interact directly with the display. According to Müller et al. curiosity is one of the most motivational aspects to achieve this. Due to the fact that the interaction may take place in public, they also claim that it is very important to preserve the privacy of each single user. It should not be possible to connect the displayed information to one specific user at any time.

COLLABORATIVE NEWSPAPER

The idea of our collaborative newspaper was to enable several users to read text displayed on a public screen at the same time. As space is limited, numerous texts might not fit the screen dimensions. Hence scrolling would be essential to finish reading a displayed text. For this purpose we developed an adaptive scrolling algorithm that scrolls a text, currently read by a person, aligned to her standard reading speed. In this paper we only consider vertical text scrolling. Our approach faced two challenges: the standard reading speed of a user and where the user is looking in the text, more precisely her reading location. Furthermore, proper scrolling of the text has to be ensured for a single user, as well as for multiple users reading the same text.

Adaptive Scrolling

We are using head-mounted eye trackers as the only input device to track people's gaze. To identify and track the screen in space, on-screen visual markers are used. With this information, the raw gaze coordinates can be mapped to the correct on-screen gaze coordinates and thus the current location in a text.

Figure 2 gives an overview of the adaptive scrolling approach. The adaptive scrolling algorithm has knowledge about the complete display layout, i.e. the number of displayed texts, the text length, as well as the width, height and position used to display the text. According to this knowledge and the input data from the eye trackers (two-dimensional coordinates of the users' gaze locations), the algorithm creates *view ports* (i.e. the scrolling views) for every user. Every view port has the following attributes: *state, y-position, height* and *scroll offset* (in y direction). The state can be *extended* or *non-extended*, which is defined by the space between *view ports*.

The algorithm distinguishes between *virtual* view ports, representing the user's view and defining the text area which

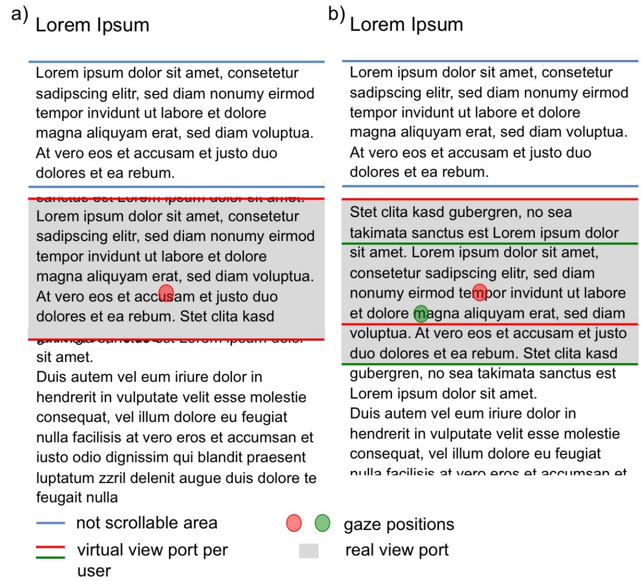

Figure 2. Collaborative newspaper system. a) single-user mode with one virtual and real view port. b) multi-user mode with overlapping virtual view ports merged in one real view port.

should be displayed on the screen, and *real* view ports, where the scroll area is actually shown on the screen (see (a) of Figure 2). A mapping between the two types of view ports ensures that the scroll areas are correctly mapped to the displayed texts. If two virtual view ports are overlapping, they are mapped to one real view port displaying a merged version of them (see (b) of Figure 2). The positions of the real view ports depend on the distances between the presented text lines of the respective view ports. This is done to preserve the offsets of the scroll views and to include the different states.

The number of readers able to read a text simultaneously is limited by the size of the view ports. Pilot studies have shown that it was sufficient to have a size of six text lines. However, this depends on other factors like screen size, font and use case.

Implementation

Our system consists of four components: monocular head-mounted eye trackers[1], a large scale front-projected display wall, a laptop needed for each eye tracker and desktop computer driving the screen. The laptop computers are processing the eye tracker input stream and transmit the gaze positions to the desktop computer for further processing. The desktop computer runs the collaborative newspaper application including the adaptive scrolling algorithm. The computers are connected via a closed local network. The software controlling the eye tracker is based on PUPIL's open source platform [7], developed in Python. The collaborative newspaper application is also implemented in Python. PyGame[2] is used to implement the graphical user interface. For display identi-

[1] `http://pupil-labs.com/pupil`
[2] `http://http://pygame.org/`

fication we are using PUPIL's built-in visual marker tracking, that is inspired by ArUco[3].

The main idea of the implementation is to keep the user reading in the middle third of her personal view port. This is ensured by adjusting the scrolling speed in such a way that the gaze always stays in the middle part of the displayed text. There are two thresholds limiting the reading section in the middle in order to determine when and how to adapt the scrolling speed. If the gaze falls below the lower threshold the scrolling speed will be accelerated to bring the user's eye gaze back into the middle third. Analogously, the scrolling is decelerated if the gaze point is above the upper threshold to give the user the opportunity to get back into the reading section.

The gaze data from each eye tracker device provides discrete input from every user which is essential to realize scrolling for multiple users. According to these data, each scrolling speed per eye tracker is controlled individually for every user.

Reading a text in its full length is defined by looking at each line from left to right at least for languages using latin script. The lines are read from top to bottom. So it is sufficient to consider the y-position of the user's eye gaze whether it can be scrolled down. According to Kumar et al. [8], the scrolling rate will be increased if the gaze is below a lower threshold, which is at 60% of the screen height. In contrast to the Eye-in-the-middle approach there is no middle part in our scenario. The view port of one user shows only six lines. Consequently, there is not enough space to keep the scrolling speed constant over a longer time period. Therefore it is more efficient to constantly update the scrolling speed and let the user continuously read the moving text in the area around the lower threshold. Furthermore, we choose the same line for both the lower and upper threshold and decrease scrolling speed as soon as the gaze is above it. Another difference to the sample algorithm is that we allow upward scrolling which is triggered by looking at the first displayed line. This extension is essential in our implementation, because due to the limited space, the text of interest may probably outside the view when the user would not know a word, misunderstood something or was distracted from reading.

EXPERIMENT

We conducted a controlled laboratory experiment to evaluate our developed approach with respect to the standard reading speed of people.

Modes

Figure 3 shows an illustration of the experimental setup. All texts had roughly the same length, except the one of mode *Baseline*, that had to fit the size of the column length. Every participant had to read the same texts. In our experiment we had five different modes in total, which are divided into tow baseline modes and three test modes:

- *Baseline (BS)* - record each participant's standard reading speed of a text fitting the vertical space. Each person is reading *T2* without scrolling and standing at location *L2*.

[3] **http://www.uco.es/investiga/grupos/ava/node/26**

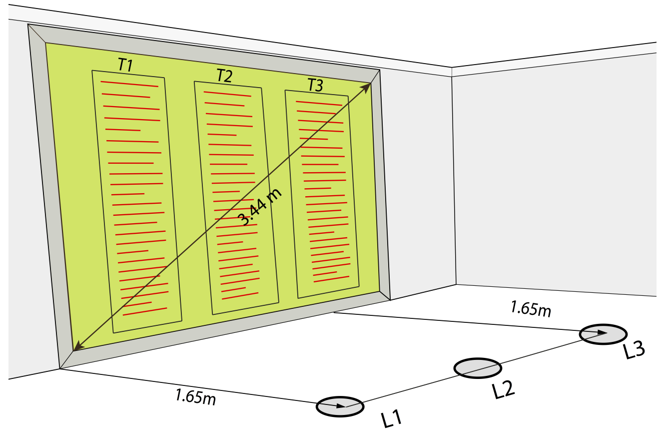

Figure 3. This figure shows the experimental setup. The three text columns T1, T2 and T3 were displayed on a large front-projected display wall with a size of 3.44 meters in diagonal. The three stationary reading locations L1, L2 and L3 were at a distance of 1.65 meters to the display.

- *Baseline Scroll (BSS)* - record the reading speed of the participant, while she is reading *T2* supported by the scrolling approach for the first time. In this case the participant is standing at location *L2*.
- *Single Scroll (SS)* - the mode is analog to mode *BSS*, but the participant is familiar with the system at this time.
- *Group Scroll (GS)* - three participants are standing in front of the projected screen and are reading the texts right in front of their location (L1 to T1, etc.).
- *Multi Scroll (MS)* - this mode is analog to mode *GS*. Additionally, every text is read by two simulated readers with different reading speed.

Task & Procedure

We implemented a simple reading task in which participants had to read a text of a predefined length on a projected display. There was no feedback provided to the participants about their current computed gaze position on the screen, as it would affect the visibility of the text. Participants were instructed to read the complete text and trigger a button via dwell time when they were finished.

For each mode, the participants started with a standard 9-point calibration from the same location where they were going to read the text from. After each mode, each participant filled out a NASA-TLX [5] questionnaire for each mode to record the work load. At the end of the study we asked for demographic information.

We collected gaze data from the eye tracker and the timestamps when participants started and finished reading. All data was sampled at 30 Hz. Furthermore, we recorded the number of words of each text.

Experimental Design

We used a within-subject design for our experiment with independent variables *BS, BSS, SS, GS* and *MS*. The participants

	M	SD	p
$wrt_{BS,SS}$	1.72	1.27	> 0.32
$wrt_{BS,GS}$	1.84	1.33	> 0.20
$wrt_{BS,MS}$	1.58	0.87	> 0.16

Table 1. Mean values (M), standard deviations (SD) and p-values of the computed weighted reading trends between baseline mode BS and the test modes.

were grouped into teams of three persons. At first every participant completed the modes *BS, BSS* and *SS*. The modes *GS* and *MS* were done by all participants of each group at the same time for a multi-user scenario.

Apparatus

As shown in figure 3, we used a large front-projected screen with a size of 2.75×2.07 meters (3.44 meters in diagonal). The three locations (*L1, L2* and *L3*) were located in parallel to the projected display at a distance of 1.65 meters. On the projection, the same layout was used in every mode to show the texts. We used a visual marker tracking to identify the display and track people's gazes on the screen. The system was an Intel Core i5 4x 3.20 GHz CPU with 8 GB of RAM, and a NVIDIA GeForce GTX 660 Ti graphics card. The operating system was Windows 8 and the software was written in Python. The experiment input devices were three head-mounted eye trackers connected to Mac Book Pro Laptops.

Participants

15 participants (7 female and 8 male) between 19 and 50 years (mean = 22.47, SD = 7.86) were recruited from a local university campus. 5 participants had previous experience with mobile eye trackers, and none reported any form of visual impairments. Every group consisted of 3 persons, with at least 1 female.

RESULTS

In the following we present the results of the experiment with respect to the two baseline modes (Baseline: BS; Baseline Scroll: BSS) and three test modes (Single Scroll: SS; Group Scroll: GS; Multi Scroll: MS) for reading speed. Then additional subjective feedback of a NASA TLX test is reported.

Reading Speed

We investigated the reading speed of each mode by recording the words per minute WPM_{mode} (1) as the quotient of the number of words of the text and the time t_r the participants needed to read the text for each mode respectively:

$$WPM_{mode} = \frac{\#words}{t_r} \tag{1}$$

Then we computed weighted reading trends $wrt_{BS,mode}$ and $wrt_{BSS,mode}$. Those indicate either equality, decrease or increase of the participant's reading time t_r between the baseline modes *BS* and *BSS* and the test modes *SS, GS* and *MS*:

$$wrt_{(BS|BSS),mode} = \frac{WPM_{(BS|BSS)}}{WPM_{mode}} \tag{2}$$

$$wrt_{(BS|BSS),mode} \begin{cases} < 1 & t_r \text{ decreased} \\ = 1 & t_r \text{ equal} \\ > 1 & t_r \text{ increased} \end{cases}$$

To assess the effect of the scroll algorithm approach on the reading speed, we did a one-way ANOVA with a Bonferroni-corrected post-hoc analysis across all modes for $wrt_{BS,mode}$. Furthermore, we used Greenhouse-Geisser correction in cases where sphericity had been violated. Table 1 shows the mean values and the standard deviations. The table further shows that the reading speeds of people were not negatively affected by the adapted scrolling technique. Moreover, we observe the positive trend, that the reading speed increases. However, we found no significance on reading speed.

Further, we investigated whether there is an effect between the different modes using the adaptive scrolling algorithm. Therefore we did the same one-way ANOVA as before across all modes, except *BS* for $wrt_{BSS,mode}$. Table 2 shows the mean values and the standard deviations. The table further shows that the reading speed did slightly increase if we assume a baseline with activated adapted scrolling algorithm. We did not find any significance on reading speed between the different modes.

	M	SD	p
$wrt_{BSS,SS}$	1.59	1.82	> 0.95
$wrt_{BSS,GS}$	1.09	0.23	> 0.95
$wrt_{BSS,MS}$	1.01	0.28	> 0.95

Table 2. Mean values (M), standard deviations (SD) and p-values of the computed weighted reading trends between baseline mode BSS and the test modes.

Impact on qualitative measures

We wanted to estimate how convenient text reading is, supported by our adaptive scrolling technique. Figure 4 shows the results of the answers, participants gave by filling out paper-based NASA-TLX questionnaires for each mode.

Overall, participants rated their mental, physical and temporal demand, as well as effort and frustration very low. Especially the temporal demand was rated higher in all modes than in *BS*. Finally, performance was rated very high for all modes.

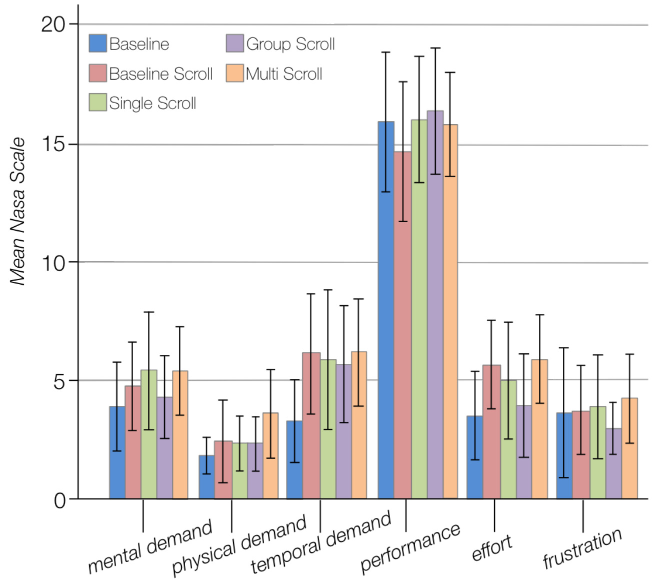

Figure 4. This figure illustrates the NASA-TLX sub-scales for each mode with the average values on the y-axis and the sub-scales on the x-axis.

To evaluate the effects of the modes quantified with NASA-TLX, we executed a one-way ANOVA with a Bonferroni-corrected post-hoc analysis, but there was no significance for any of the variables across all modes.

DISCUSSION & LIMITATIONS

Our results show that - on a large projected display - the adaptive scrolling approach does not negatively influence people's reading speed. Moreover, our results are showing a trend, that the reading speed does slightly improve, even if we found no significance across the tested modes. However, the most promising result is the fact that even in *MS* the reading speed is slightly better than in *BS* and *BSS*. In *MS* two additional simulated readers with different reading speeds were added to cause as much interference as possible by simulating multiple readers on the same display wall. Then, for each text, there were up to three scrolling areas at the same time. The experimental results show that there is no significant difference with regard to the reading speed between one single-user compared to multiple-user reading text on large public screens.

All participants rated the usage of the adaptive scrolling algorithm as hardly demanding. Surprisingly for *temporal demand* there is a visible difference between *BS* and all other modes, although the evaluation of the readings speeds showed the opposite. This might be caused by the text lengths which were about twice the length of the *BS* text. Furthermore, the effort and frustration level is very low across all modes which supports the ease of use and low instrumentation of our approach. Finally the fact, that effort and frustration level for *MS* is just irreducibly higher as for *BSS*, shows the ability of the system to deal with multi-user scenarios.

Despite the good performance of our developed adaptive scrolling technique, it comes with several limitations. The approach is dependent on the layout of the text, i.e. the number of people reading the same text simultaneously is limited. Nevertheless, our adaptive scrolling technique enables multi-user reading after all. Furthermore it is necessary for the algorithm, that people start to read the text from the beginning. So it is not possible to spontaneously start reading at any place in the text and be supported by the scrolling technique.

FUTURE WORK

The setting presented in this paper uses mobile head worn eye trackers, which are not suitable for real public settings because they are connected via cable to the system. So in the future the mobile eye trackers might be replaced by remote systems.

Although the presented algorithm works convincing in our tests, there is still a lot of room for improvements in our collaborative newspaper application. One possible extension could be a layout depending on the situation. So it could be possible to adapt the appearance of the system, e.g. to the current light conditions by providing different layouts for day and night. The foundation for this feature is already implemented.

As mentioned above, the software already provides the possibility to define different layouts. Another improvement that may be useful when displaying other kinds of articles is the option to present formatted text (using colored, bold or italic text). This would enlarge the expressiveness of the provided information and contribute to the system's attractiveness.

The texts of the articles are static and need to be updated manually. To address the widest range of users, a dynamic content management system would be very useful. Thus, unpopular or out-dated articles could be replaced by new ones, giving the users the chance to read new content which they may be more interested in. After reading an article, the users should have the possibility to rate it so that others can get a first impression of its quality. These visible ratings can also be included in choosing the articles that should be replaced or updated, because they are not that appropriate for the current users and may predict which articles may be more interesting.

A first study to evaluate the system has already been conducted. With experimental results of more studies with bigger audience it could be possible to see whether the algorithm works for a broader publicity in order to adapt the system to the users' needs.

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