ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2007. No. 2(74)
ELEKTRONIKA IR ELEKTROTECHNIKA

MEDICINE TECHNOLOGY
T 115
MEDICINOS TECHNOLOGIJA

Visualization of Eye Gaze Data using Heat Maps

O. Špakov
*Department of Computer Science, University of Tampere,
FIN-33014 Tampere, Finland, tel.: +358 3 35518556, e-mail: oleg@cs.uta.fi*
D. Miniotas
*Department of Electronic Systems, Vilnius Gediminas Technical University,
Naugarduko st. 41, LT-03227 Vilnius, Lithuania, tel.: +370 5 2744758, e-mail: darius.miniotas@el.vtu.lt*

Introduction

The relation between eye movements and internal brain processes (thinking, cognition, etc.) is known for a long time. The first eye trackers served sociologists as the "window into human mind".

Today, usability testing is widely used to determine, for instance, the quality of web site designs [1]. Such a testing usually involves many participants having to perform a number of tasks. An experimenter observes the participants while a camera records their eye movements. The time to complete the task is usually recorded along with the type and number of errors as well as the subjective ratings for ease of use [2].

From the collected eye-movement data researchers can determine whether users were looking at the appropriate objects, differentiate reading from scanning for particular words or phrases, learn the relative intensity of the user's attention to various parts of a web page, and find out whether the user was searching for a specific item [3].

Techniques for Eye Gaze Visualization

There is a range of techniques for visualizing the data recorded by an eye tracker. The most straightforward of those provide a simple plot of the pupil's horizontal and vertical coordinates against time. Other techniques plot raw eye movements in 2-D with the stimulus image as the background. Again, this method is still extensively used by researchers, and is one of the easiest-to-implement techniques of the visualization [4].

More advanced visualization techniques use the so-called fixation maps to present the information in a more consistent manner (Fig. 1). Fixation detection algorithms are employed to convert the raw data into a set of fixations. Traditionally, fixations are represented by circles, and saccades are represented by lines connecting the circles.

Fig. 1. Fixations visualized as circles (University of Trier)

A modern visualization technique using heat maps was derived from the fixations maps based technique (Fig. 2). Heat maps better separate different levels of observation intensity than fixation maps. Color mapping is usually selected so that the longer the observation, the warmer the color used to represent it.

A modification of the technique uses opaque heat maps with no shadow over the unobserved areas (Fig. 3). However, this kind of visualization hides details of the stimulus image. This tends to hinder the analysis.

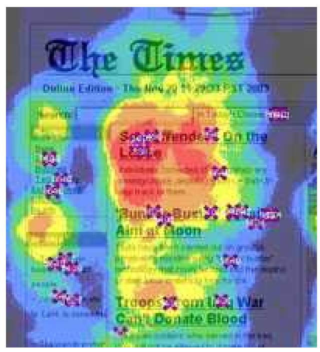

Fig. 2. Heat map with fixation marks (EyeTools)

Fig. 3. Heat map with opaque coloring (BeGaze from SMI)

In this paper, we present another version of the heat-map visualization technique. The proposed approach facilitates visualization by allowing the transparency of the heat map to depend on the gaze data itself.

Modifying Heat Maps

Heat maps provide a quick glance on the data distribution over the picture observed during an experiment. Traditionally, heat-maps visualize the background image with overlaying semi-transparent colors. Most such visualizations use red color for highlighting the most intensively observed areas, and blue or black for coloring the unobserved parts of the picture. Colors in a heat map change gradually, and the display resembles a topographic image with hills and valleys.

Presenting the unobserved areas in black can be regarded as shading the image. Usually, the shadows do not totally hide the background image, but only dim it.

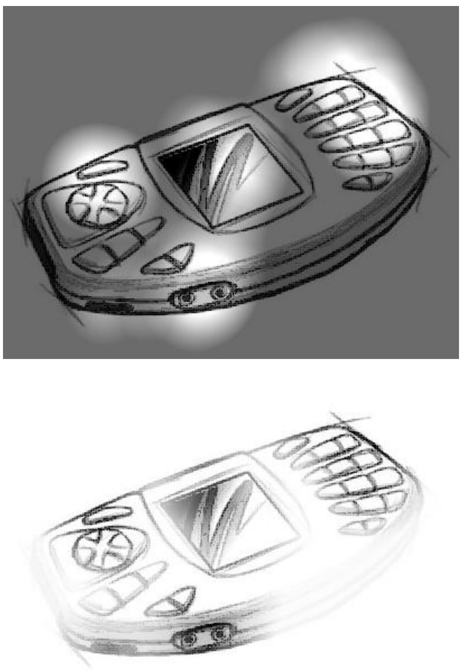

Fig. 4. Heat-map visualizations using a) shadow, b) fog

Our approach substantially extends the notion of heat maps. Here, the term “heat map” pertains to all the visualizations where eye gaze data adds transparency, or some color, to the background image. In our current implementation, the background can be partly or totally hidden by a shadow or fog (Fig. 4).

The initial opaqueness of an image is adjustable. Transparency can be presented in either the traditional way (using shades of gray), or employing some color scheme. In the latter case, color in a particular location conveys the intensity of the observation similar to the transparency level in a gray-scaled heat map.

The intensity is proportional to the duration of the observation. Thus, longer fixations add more transparency than shorter ones. A fixation longer than some threshold makes the display totally transparent at the location it is superimposed.

In fact, the measured gaze position during an observation contains only a single point that covers only a relatively small part of the display. Meanwhile, the actual observation involves a whole group of pixels.

Therefore, we suggest that every pixel in the heat map related to a particular gaze location “extends transparency” to the neighboring area. The radius of this area should be a few degrees of arc and subject to the user’s choice. We also propose three alternative forms for the function of the transparency distribution. One of these is a simple linear relationship, whereas the other two are nonlinear (a sum of linear and sine wave, and a Gaussian).

Visualization Options

There is a dialogue window in our software that contains the controls for setting the type of transparency and its distribution (Fig. 5). Each fixation adds a certain amount of transparency in each point of visualization. However, only the *Gaussian* distribution covers all the display, whereas the other distribution types affect only the area in the vicinity of the fixation. The shapes of influence for all the distributions available are shown in Fig. 6. In this figure, the *x* axis denotes distance from a fixation, and the *y* axis denotes influence on the transparency.

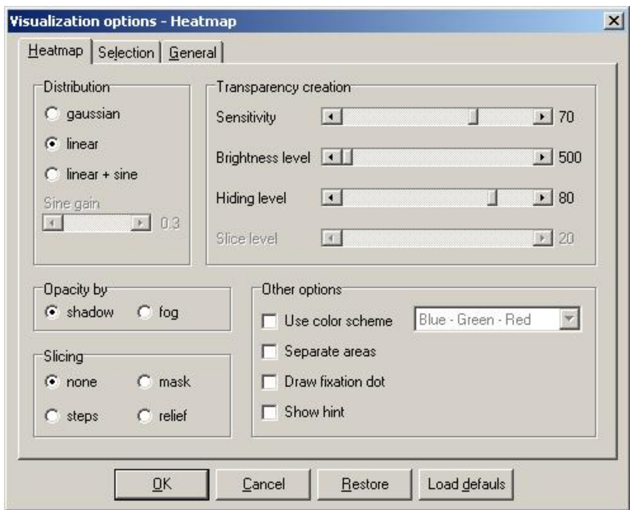

Fig. 5. Options of the visualization *Heat Map*

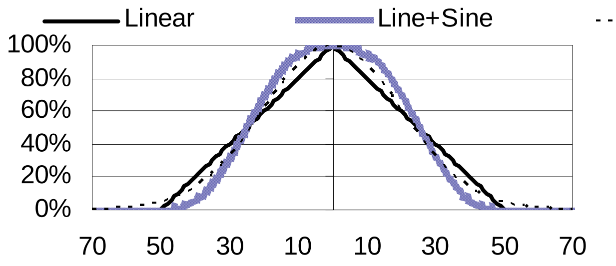

Fig. 6. Shapes of influence to transparency of a single fixation

The controls of the second group (*Transparency creation*) allow adjusting the influence of each fixation on the transparency. *Sensitivity* (*S*) denotes the radius of influence (*Linear* and *Linear + Sine* distributions), or variance σ^2 (*Gaussian* distribution).

Brightness level (*BL*) is used as the gain for the distribution functions. It shows the minimum fixation duration (FD_i) that makes the view totally transparent at the place of its occurrence.

Hiding level (*HL*) denotes the initial level of the shadow's or fog's opaqueness. Totally hidden background of the view corresponds to *HL* of 100%.

The meaning of the last control (*Slicing level*) depends on the value of the option *Slicing*. By default, it is *None*, which means that transparency just changes by one of the distribution rules and no slicing is applied (Fig. 7a).

With the option *Steps* checked, transparency is shaped like terrain steps (Fig. 7b). The width of each step equals the value of *Step level* in pixels. The transparency rate of a step is the average of all pixels in the step.

With the option *Mask* checked, transparency lower than the value of *Mask level* is not applied to the visualization (Fig. 7c).

Finally, with the option *Relief* checked, the calculated transparency is applied only if its value is a multiple of *Relief level*. This makes visualization similar to the topographic map (Fig. 7d).

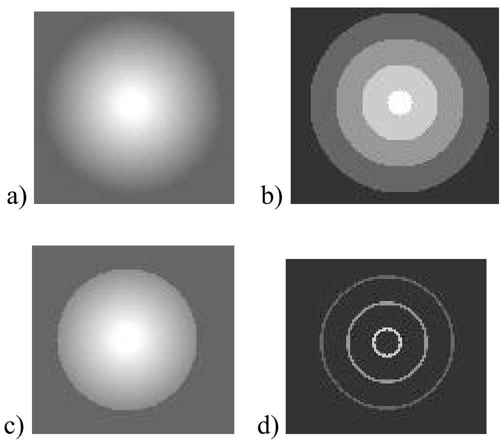

Fig. 7. Transparency mode: a) smooth, b) slices, c) mask, d) relief

The procedure for setting the transparency can be illustrated through an example. Suppose that the recorded data has *N* fixations. Transparency T_i of a single pixel at distance *D* from the i^{th} fixation in the *Linear* distribution is calculated using the following expression:

$$T_i = T_{i-1} + \begin{cases} \dfrac{S-D}{S} \cdot \dfrac{FD_i - HL \cdot BL}{BL}, if\,(D \le S), \\ 0, if\,(D > S). \end{cases} \tag{1}$$

For the Gaussian distribution, *S* is equivalent to σ^2. The multiplier before the exponent keeps $T = 100\%$ when $FD = BL$ for any value of *S* and *BL*:

$$T_i = T_{i-1} + \frac{FD_i - HL \cdot BL}{BL} \cdot e^{-\frac{D^2}{2S}}. \tag{2}$$

In all the expressions, T_i is the cumulative transparency after the first *i* fixations. Before any fixation can contribute to transparency, $T_0 = HL$. The value of T_N cannot be less than 0, or greater than 1.

Hiding can appear as a shadow or fog. It is defined via the option *Opacity*. From the implementation point, shadowing means covering the background picture in black, whereas fogging is covering it in white.

The *Other options* group contains the rest of the controls. If the flag *Use color scheme* is checked, the semi-transparent areas appear in color. The coloring schemes are displayed in the drop-down list next to this flag. The left-most color is applied to the areas with low transparency, whereas the right-most color is applied to the fully transparent areas. Current implementation of our software supports the following color schemes:

- Blue – Green – Red – White;
- Blue – Green – Red;
- Blue –Red;
- Green – Yellow – Red – White;
- Green – Yellow – Red.

If the *Separate areas* flag is checked, a fully or partly transparent area is separated by an inverted-color boundary from the area with the initial transparency level. However, this flag has no effect when applying any of the slicing options.

If the *Draw fixation dot* flag is checked, small white or black dots representing the fixations are displayed. Finally, if the *Show hint* flag is checked, a hint appears when moving the mouse cursor over the display that shows the transparency level and coordinates of the cursor.

Conclusions

This paper proposes a technique to facilitate visualization of eye gaze data gathered during both basic experimental studies on eye movements and usability studies on products and displays. The technique is an extension of the heat-map based visualization method. Its unique feature is that eye gaze data modulates the transparency of heat maps.

In other words, eye gaze is allowed to add transparency to the shaded background. This way the details of less relevance are hidden (using either shadows or fog) from the view, whereas more intensively observed areas become more conspicuous through increased transparency.

Usability studies on various products proved our version of the heat-map visualization technique quite useful for researchers [5, 6].

References

1. **Cowen L., Ball L. J., Delin J.** An eye movement analysis of web page usability // Proceedings of Human-Computer Interaction HCI'02, 2002. – P. 317-335.
2. **Jacob R. J. K., Karn K. S.** Eye tracking in human-computer interaction and usability research: ready to deliver the promises // J. Hyonä, R. Radach, H. Deubel (Eds.), The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research. – Elsevier Science, 2003. – P.573–605.
3. **Crowe E., Narayanan N. H.** Comparing interfaces based on what users watch and do // Proceedings of the Symposium on Eye Tracking Research & Applications. – ACM Press, 2000. – P. 29–36.
4. **Duchowski A. T.** A breadth-first survey of eye-tracking applications // Behavior Research Methods, Instruments, and Computers, 2002. – Vol. 34. – P. 455–470.
5. **Räihä K. J., Aula A., Majaranta P., Rantala H., Koivunen K.** Static visualization of temporal eye-tracking data // Lecture Notes in Computer Science, 2005. – Vol. 3585. – P. 946–949.
6. **Koivunen K., Kukkonen S., Lahtinen S., Rantala H., Sharmin S.** Towards deeper understanding of how people perceive design in products // Proceedings of Computers in Art and Design Education. – Copenhagen, Denmark, 2004. – P. 139–146.

Submitted for publication 2006 11 16

O. Špakov, D. Miniotas. Visualization of Eye Gaze Data using Heat Maps // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 2(74). – P. 55–58.

Usability testing is widely used today to determine, among other things, the quality of web site designs. To help the researchers, a number of techniques have been suggested for visualizing the eye tracker's data. Using one of the most popular techniques, gaze fixations are plotted in 2-D against the stimulus image in the background. However, there is an alternative visualization technique, based on the heat map paradigm, which offers additional benefits by better separating the different levels of observation intensity. We present a modified version of this technique to facilitate visualizations by allowing the transparency of the heat map to depend on the gaze data itself. In our version, transparency is presented in either the gray scale, or employing some color scheme. The intensity is proportional to the duration of the observation. Thus, longer fixations add more transparency than shorter ones. Conversely, the least observed areas are hidden by a shadow or fog. We also propose three alternative forms for the function of the transparency distribution. One of these is a simple linear relationship, whereas the other two are nonlinear (a sum of linear and sine wave, and a Gaussian). Ill. 7, bibl. 6 (in English; summaries in English, Russian and Lithuanian).

О. Шпаков, Д. Миниотас. Визуализация информации о движениях глаз с помощью термокарт // Электроника и электротехника. – Каунас: Технология, 2007. – № 2(74). – С. 55–58.

В настоящее время для оценки качества дизайна интернетных сайтов их пригодность к использованию всё чаще проверяется специальными тестами. Для визуализации данных от регистратора движений глаз было предложено несколько методов. Фиксации взглядов чаще всего рисуются в двумерном пространстве поверх изображения стимула. Однако больше достоинств имеет альтернативная визуализация, напоминающая термокарты, которая позволяет лучше отличить уровни с различной интенсивностью просмотра. В настоящей работе предлагается модифицированный метод, с помощью которого прозрачность изображения становится зависимым от данных регистратора движений глаз. Различные уровни прозрачности подвергаются цветному кодированию или изображаются тональностями серого. Конкретный уровень прозрачности зависит от продолжительности просмотра. Таким образом, более длинные фиксации взглядом увеличивают видимость стимула на их фоне больше чем фиксации покороче. В то же время, меньше всего внимания получившие места изображения прячутся в "тени" или в "тумане". В работе так же предлагаются три разновидности функции распределения прозрачности изображения. Одной из них является линейная зависимость, а остальные две зависимости нелинейны (т.е., сумма линейной и гармонической функций, а так же функция нормального распределения). Ил. 7, библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

O. Špakov, D. Miniotas. Informacijos apie akių judesius vizualizacija naudojant termožemėlapius // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. –Nr. 2(74).– P. 55–58.

Pastaruoju metu interneto tinklalapių dizaino kokybė vis dažniau vertinama pagal jų tinkamumo naudoti tyrimo rezultatus. Akių judesių registratoriaus duomenims vizualizuoti pasiūlyta keletas metodų. Žvilgsnio fiksacijos paprastai braižomos dvimatėje erdvėje kartu su stimulo vaizdu jų fone. Tačiau pranašesnė yra alternatyvi, termožemėlapius primenanti vizualizacija, leidžianti geriau atskirti skirtingo stebėjimo intensyvumo lygius. Šiame darbe siūlomas modifikuotas metodas, kurį taikant vaizdo skaidrumas tampa priklausomas nuo akių judesių registratoriaus duomenų. Skirtingi skaidrumo lygiai koduojami spalvomis arba pateikiami pilkoje skalėje. Konkretus skaidrumo lygis priklauso nuo stebėjimo trukmės. Taigi ilgesnės žvilgsnio fiksacijos padidina jų fone esančio stimulo matomumą labiau nei trumpesnės. Tuo tarpu mažiausiai dėmesį patraukusios stimulo vietos paslepiamos „šešėlyje" arba „rūke". Darbe taip pat siūlomi trys vaizdo skaidrumo pasiskirstymo funkcijos variantai. Vienas iš jų – paprasta tiesinė priklausomybė, kiti du – netiesinės priklausomybės (t. y. tiesinės ir harmoninės funkcijų suma bei normalinio pasiskirstymo funkcija). Il. 7, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).