Achieve Perfect Eye Tracking Error Correction Using Linear Regression

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Eye tracking data is rarely perfectly accurate. There is almost always a disparity between a person's actual gaze location and the location recorded by the eye tracker. Disparities that are constant over time are systematic error, which may be caused by imperfect calibration, head movement, and other sources. Systematic error poses a serious problem for eye tracking research, as it leads to misinterpretations of the data and incorrect conclusions about human behaviors.

Our lab has introduced a couple of methods in the past to help reduce eye tracking systematic error [1, 2]. Although these methods are increasingly widely recognized by the eye tracking research community [3, 4, 5], they do not fully address the error in all situations. Particularly, they do not perform well for systematic error that varies at different locations on the display, which might be common for software or experiments that fully utilize an entire display as opposed to a small area. This research introduces a method that almost perfectly corrects error across the entire display by combining our prior methods with linear regression. To demonstrate the effectiveness of the method, it was applied to clean the eye tracking error for a visual search experiment, which uses a large screen that approaches the limit of a dual-camera eye tracking system.

Measure Systematic Error Across Display

Little eye tracking research reported systematic error, let alone how the error changes across the display. In our recent visual search experiment, we used the required fixation location (RFL) technique [1] (details described later) to measure the error associated with some fixations. This data helped reveal the nature of systematic error and its relation to fixation location.

The data showed that the error changes continuously across the display, and this change can be roughly approximated by a two-dimensional quadratic function. This is a critical observation because a previous method [2] assumed that the error changes abruptly and discretely from one region to another, and the analyst must examine the eye movement data visualization to find the individual regions in which the error stayed relatively constant. But because it is now shown that the error changes continuously in a somewhat predictable manner, it should be possible to find an equation to accurately describe the error.

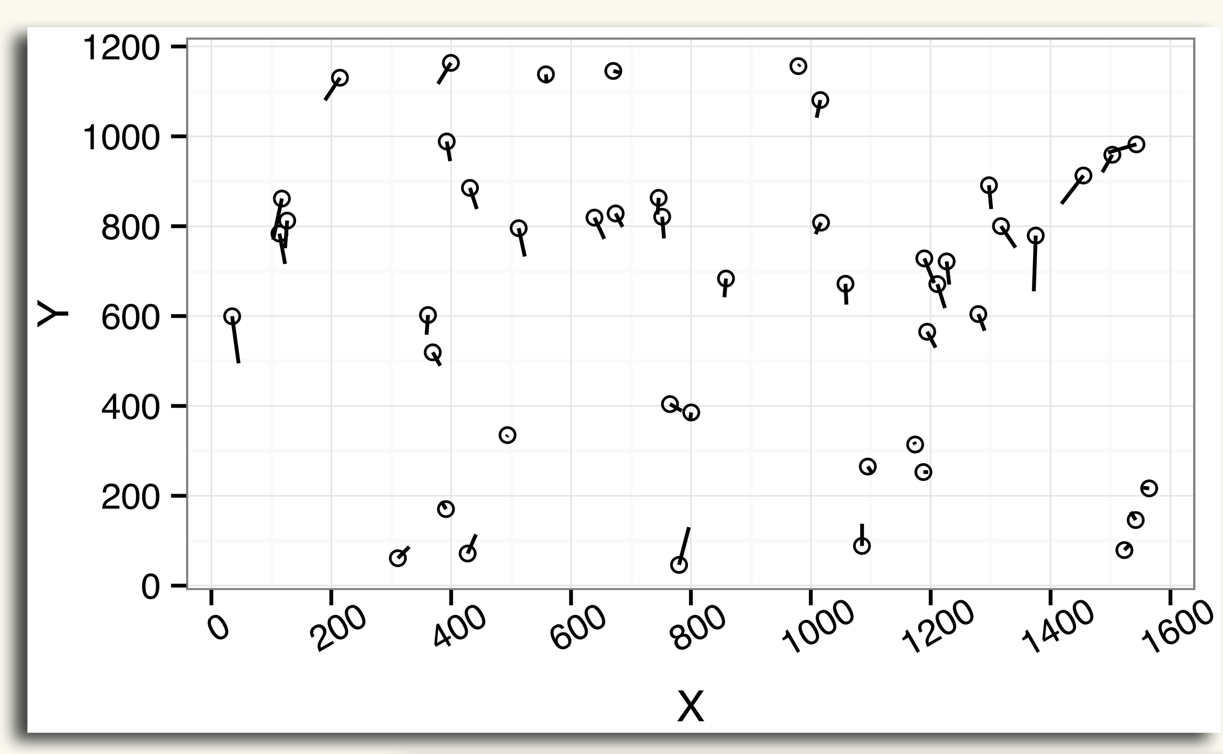

Figure 1. Systematic error varies from one location to another.

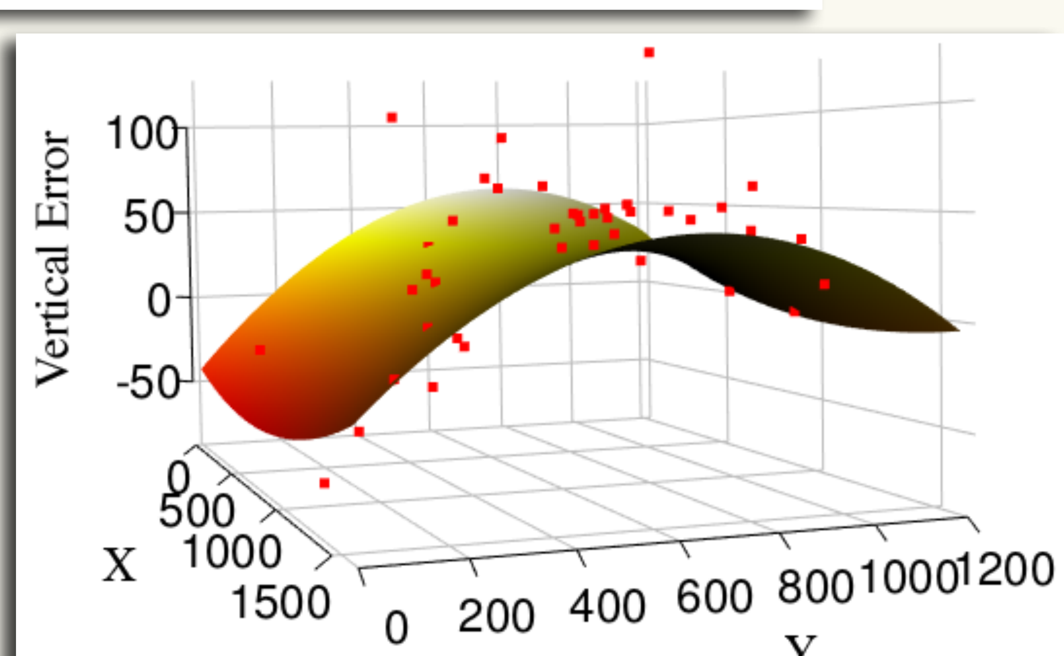

Figure 2. The error closely follow a quadratic surface.

The Quadratic Error Correction Equation

Instead of finding the equation that describes the error, we went one step future to directly estimate the fixations' true locations based on the observed locations. We propose the following equation:

$$x' = a_0 + a_1x + a_2x^2 + a_3y + a_4y^2 + a_5xy$$
$$y' = b_0 + b_1x + b_2x^2 + b_3y + b_4y^2 + b_5xy$$

where x, y are the observed coordinates, x', y' are the corrected coordinates, and a_i and b_i, i=0 to 5, are the parameters that need to be determined from the eye movement data with linear regression. The eye movement data that are used to estimate the parameters are the ones whose true locations (x', y') can be inferred. The source of such data depends on the experiment design, and it is possible that one source is more reliable than others. This difference in reliability can be coded as weights when submitted to regression.

Apply to Visual Search Experiment

The error correction technique was applied to the eye movement data of our recent visual search experiment. The task of the experiment was to locate an object on the display that has the given identification number. Some features of the target object such as color, shape and size may be given to facilitate search. The experiment used a 39º (degrees of visual angle) by 30º display, which was very close to the 40º tracking limit of our 120 Hz LC binocular eye tracker. Perhaps due to this reason, we found substantial eye tracking error around the edges of the screen, but little or no error at the center. This changing systematic error may prohibit previous error cleaning methods, but it is ideal for testing the new regression-based error correction technique.

For this experiment, the eye movement data that were used to fit the quadratic equations came from two sources. The first source was the RFL fixations that occurred when the search target was clicked. Because the experiment imposed a point-completion deadline [6] which required the participant to click the target in a short amount of time once the mouse is moved, participants had to look at the target to ensure clicking on the right place at the end of a fast pointing movement. The second source of the eye movement data came from the trials that only gave an identification number as the search cue. Under this condition, the participant had to look at the text labels (0.26º in height) to determine if an object was the target. Because small text-labels need to be perceived using focal vision [7], it is relatively safe to assume that fixations occurred in these conditions should be assigned to their nearest text labels. Because we were more confident about the accuracy of the first source, it was assigned a weight of ten when submitted to regression whereas the second source was assigned a weight of one.

Both eye data visualizations and a quantitative analysis show substantial improvement brought by the error correction. The visualizations (Fig. 3) show that the corrected fixations are much closer to the center of the objects, and the amount of correction is properly adjusted from one location to another. The quantitative analysis (Fig. 4) show that before correction, the median error of many sessions were between 1º and 2º (or -1º and -2º), whereas after correction, the median error was all aligned at zero and the range of the error become smaller too.

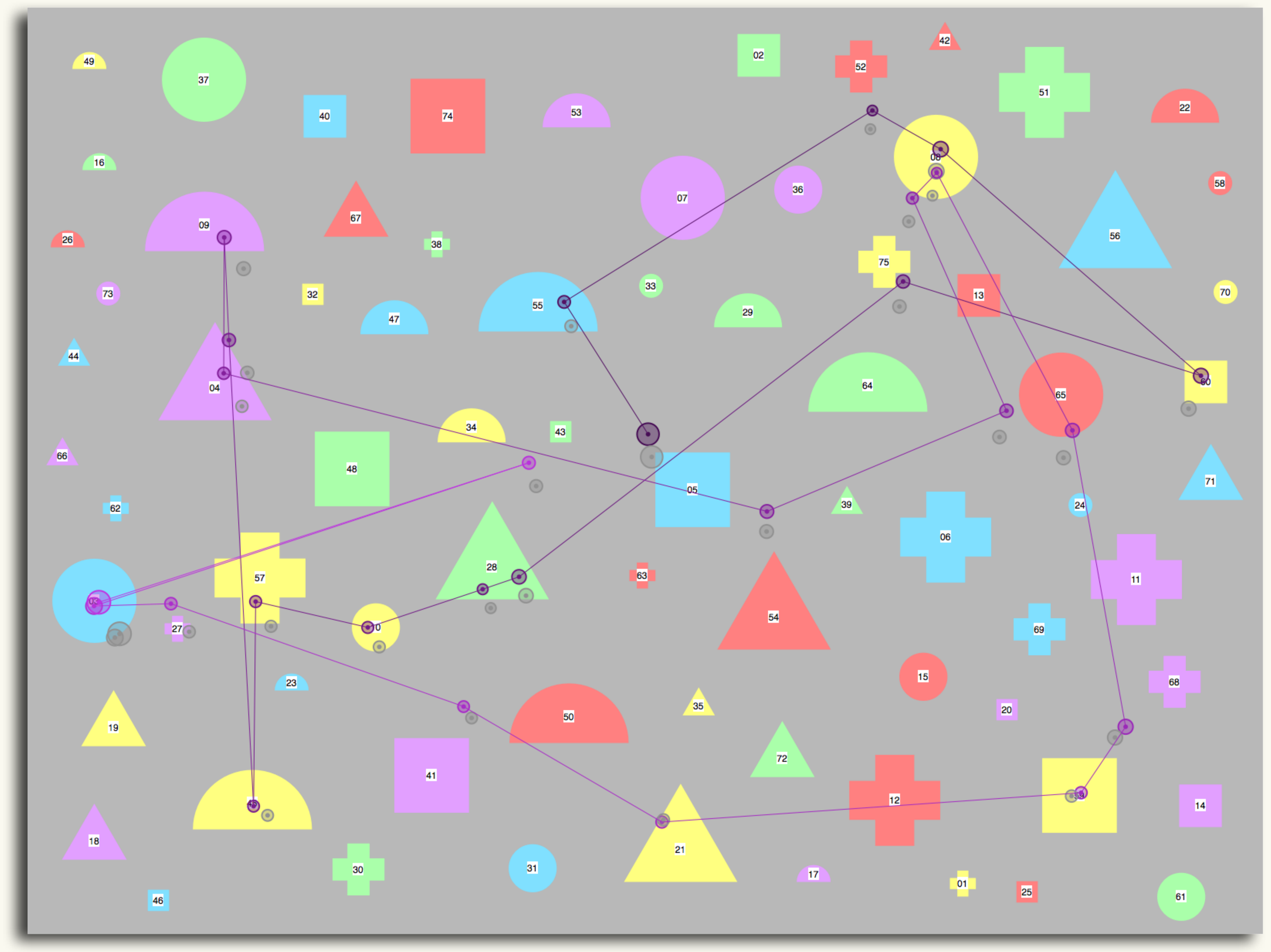

Figure 3. Eye movement data visualization of one trial. Gray circles represent the uncorrected fixations, purple corrected.

Conclusion

This research introduces a regression-based error correction technique for cleaning eye tracking systematic error that changes across the display. It provides perhaps the first set of data to show that systematic error changes continuously with respect to fixation location. A quadratic equation is then introduced based on this observation to estimate the true location of the fixations. By applying the technique to a visual search experiment, we showed a couple of methods for collecting the fixation data needed for estimating the equation parameters. The result is almost perfect eye movement data quality across a large display which reaches the tracking limit of the eye tracker.

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Figure 4. Distribution of the vertical component of the systematic error in each session, before and after error correction.