Calibration Robustness

Maintaining eye tracking quality over extended periods of time

Summary

Calibration enables an eye tracker to establish a visual relationship (mapping) between the eye camera(s) and scene camera(s). Eye tracking quality typically degrades after the first few minutes of use with traditional eye trackers. Common reasons for this loss in eye tracking quality include physically bumping or disturbing the eye tracker cameras during operation. Locarna has developed a novel method and apparatus called calibration robustness that enables the user of a mobile eye tracker to view scenes for several hours while maintaining high quality eye tracking (typically 1° - 2°). With calibration robustness, users can even temporarily remove the eye tracker from their head without the need to recalibrate.

Background

Traditional eye trackers rely on sensing the position of the pupil relative to the position of a scene camera. In order to establish the parameters that describe the mapping between the eye location as they appear in the scene camera image, or display co-ordinates, most eye tracking technologies require calibration. System calibration is typically only performed once per user at the beginning of an eye tracking session. However, periodic re-calibration may be required as environmental circumstances, such as ambient light levels, change. Furthermore, during a task, eye tracking cameras within worn accessories, such as eye glasses or helmets, often slip, get bumped, or are removed. Any of these actions reduce the accuracy of an eye tracker because the calibration relationship between the eye tracking cameras become less appropriate as a worn accessory is moved from its originally calibrated location relative to the user's eye(s). Such recalibration requires a directed effort on behalf of the user.

Mobile Eye Tracking Technology

This section describes typical eye tracking technologies, such as Locarna's PT Mini, that can benefit from calibration robustness. Figure 1 shows a typical eye tracking setup. Although calibration robustness can be applied to almost any eye tracking technology, we focus on mobile, wearable eye tracking technologies. In Figure 1, a user wears a pair of eye tracking glasses fitted with two cameras and a microphone. A scene camera records what the user sees, such as an apple in an orchard. An eye camera records the position of the user's eye, such as the centre of the pupil. A portable recording device records the video (from the cameras) and audio (from the microphone). Eye tracking algorithms within a recording device, or another type of computer, can process the collected video streams to produce eye tracking data such as eye gaze co-ordinates and visual fixations. The resulting eye tracking video logs, audio logs, and other data can then be processed and logged on a computer using software tools such as spreadsheets, statistics programs, and video analysis suites.

An eye camera can also be configured to record the location of a unique tag (marker). If the scene or eye cameras are disturbed during an eye tracking session, the eye camera will detect and record the resulting change in location. The eye tracking algorithms can respond to the disturbance to ensure eye tracking quality is maintained. This process is the essence of calibration robustness, which is described in detail below.

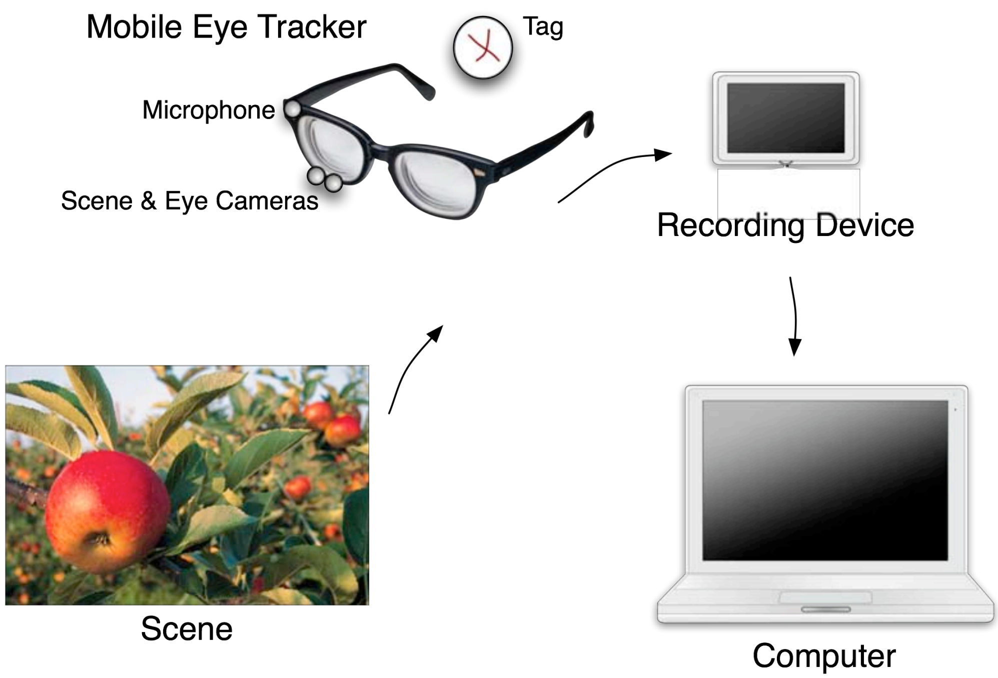


Figure 1: Typical mobile eye tracking setup

Eye Tracker Camera Calibration

This section describes typical calibration procedures to build a relationship (mapping) between eye camera(s) and scene camera(s) for a particular user. Figure 2 shows a calibration procedure where a user successively looks at nine dots arranged in a 3 x 3 grid. In this example, the nine dots fill most of the scene camera's field-of-view. The user first looks at dot 1, then dot 2, and so on until the final dot 9. The eye location and pupil centre typically change as the user looks at each dot. The pair of scene camera and eye camera locations for each of the nine dots forms a set of nine distinct relationships (mappings) that collectively define a relationship (mapping) between the user's eye pupil location and the scene camera video. Eye tracking algorithms, such as Locarna's proprietary eye gaze and visual fixation techniques, can use these resulting calibration relationships (mappings) to estimate a user's eye gaze at any pixel in a scene video frame by applying the calibration relationship (mapping) to the corresponding eye camera video frame(s). This calibration process typically takes between 30 seconds to 60 seconds.

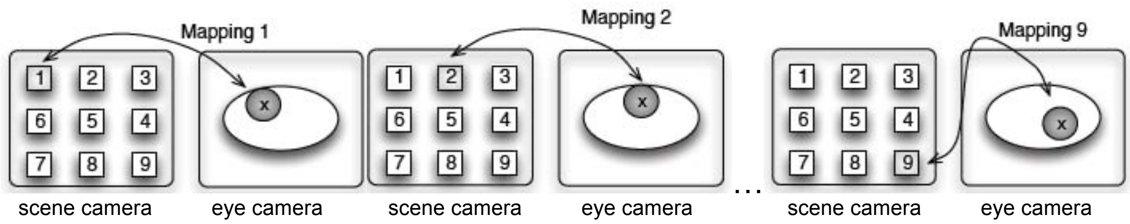


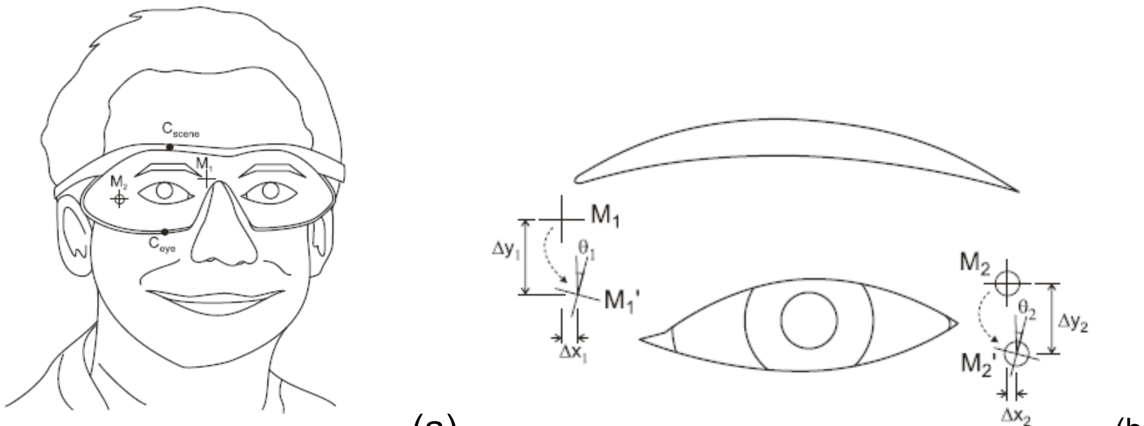
Figure 2: Typical calibration procedure

A quality calibration does not need to have nine points or have the points arranged in a grid layout. The number and physical layout of the calibration dots can vary. The most important concept in an effective calibration is that the user views a set of known points that span as much as the scene camera's field-of-view as possible. A resulting mapping between the eye pupil location and scene camera location will generally be best when the locations are near a calibration point and worst when the locations are far from a calibration point. Spanning the scene camera's field-of-view ensures that a calibration reference point is near any location where the user's eye looks during an eye tracking session. Additional calibration points facilitate high quality eye tracking even in the presence of difficult optical situations such as mappings between scene and eye cameras with significant non-linear distortions that are typical in wide angle or fish eye lenses.

Calibration Robustness

This section describes Locarna's *calibration robustness* method and apparatus for maintaining a high quality eye tracking session. Figure 3 (a) shows a person wearing a mobile eye tracker and two tags (markers), and (b) a detailed illustration of markers before and after a physical disturbance. C_{eye} and C_{scene} represent eye and scene cameras, respectively. M_1 and M_2 represent two unique markers on the user's face. These markers could be physical tags in visible or invisible spectrums, such as infrared. Also, the markers could include natural features, such as freckles, veins, or wrinkles. Multiple markers increase the accuracy of the calibration robustness technique.

Figure 3 (b) shows how two markers, M_1 and M_2, translate and rotate after the worn apparatus has experienced a disturbance such as being physically bumped. This calibration robustness method and apparatus is described in detail within US patent application No. 12/392,574, "Method and Apparatus for Tracking Eye Movement" filed on February 25, 2009. The width and height bounding box of Figure 3 (b) represents a typical video frame captured by a video camera such as C_{eye}. Before the disturbance, markers are in locations M_1 and M_2. After the disturbance, markers are in locations M_1' and M_2'. In other words, they have undergone a relative positional change. M_1 is translated Δx_1 horizontally, translated Δy_1 vertically, and rotated θ_1. Similarly, M_2 is translated Δx_2 horizontally, translated Δy_2 vertically, and rotated θ_2. In general, translations and rotations of markers, such as M_1 and M_2, are used to view transformations, such as affine transformations or non-linear mappings, from a pre-disturbance calibration matrix, T_m, to a post-disturbance calibration transformation matrix, T_m'.



(a) (b)

Figure 3: (a) A person wearing a mobile eye tracker and two tags, and (b) Illustration of the markers before and after a physical disturbance

Application Example 1

This application scenario describes how calibration robustness helps an anesthetist using a Locarna eye tracker within an operating room. Surgeries can last several hours, and a hospital work shift can last for 10 hours or more. An anesthetist may wish to wear an eye tracker to test operating room efficiency or to train medical residents. For example, an eye tracker can quantitatively record improvements in visual attention to a patient after an operating room personnel re-organization or equipment change. Alternatively, an eye tracker can record the visual patterns of the anesthetist for later comparison with a medical resident in training.

Figure 4: Eye tracking in an operating room

Without calibration robustness, eye tracking quality may degrade after the first few minutes of an operation or shift. Calibration robustness enables the anesthetist to record valuable, high-quality eye tracking data over an entire surgical operation or even an entire work shift. If the anesthetist performs multiple operations during a shift, s/he can calibrate at the beginning of the shift, and remove the eye tracking glasses between operations without needing to re-calibrate at the beginning of the next operation.

Application Example 2

This application scenario describes how calibration robustness helps a retail shopper participating in a market research field study. Retail environments are busy, dynamic environments with many challenges for traditional eye trackers. For example, specialty lighting within the retail space may interfere with the eye tracker cameras, and eye tracking gear will often get bumped or jostled within crowded stores. Nevertheless, market research professionals, and their retail clients, appreciate the superior data collected from real world field studies over laboratory or simulated environments.

Figure 5: A retail shopper viewing products

Suppose a company with a particular shirt brand wishes to know if its new style attracts significantly more customer attention than its old style. One possible test could ask retail store shoppers to purchase a shirt. The store could be stocked with style "A" for half the shoppers, and the store could be stocked with style "B" for the other half of the shoppers.

Using calibration robustness, an experimenter could approach shoppers at the entrance of the store, provide them with an eye tracker, calibrate them, then leave the shopper to choose a shirt at any time during their shopping. The eye tracking quality will not degrade during the shopping trip. Additionally, if the shopper bumps the eye tracker in a busy aisle or answers a cell phone during the study, the eye tracking will adapt to these disturbances.

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