# Reducing the Cost of Eye Tracking Systems

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## ABSTRACT

Tracking the user's eye-gaze information has been technologically possible for several decades. However, systems that track eye-gaze are still very expensive. The exorbitant price tag on commercial systems has resulted in limited use of eye-tracking technology. In this paper we examine the factors which contribute to the high costs of eye-tracking systems. We then propose several techniques and strategies which can be used to reduce the cost of these systems, ultimately resulting in more widespread use of the technology.

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**General terms:** Measurement, Performance, Design, Economics

**Keywords:** Eye Tracking, Corneal Reflection Eye Tracker, Low-Cost Eye-Tracking

## INTRODUCTION

The eyes are a rich source of information and play a crucial role in providing context and serve as a proxy for human attention and intention. Human beings (and animals) have always looked at the eyes in order to get more information as is evidenced by our daily interactions.

Gaze-tracking has been used in studies dating as far back as 1935 [3] and 1967 [12]. During these early days of eye-tracking, systems were cumbersome, invasive and not very accurate. However, with recent advancements in eye tracking technology, we can have a system that is remote, non-encumbering, non invasive and accurate to within 0.5 – 1.0 degree accuracy [11].

Current markets for eye-tracking technologies include: disabled users, web/usability analysis labs at major corporations and universities and other specialized/research uses in the fields of psychology, marketing, defense and medicine. Unfortunately, while there have been significant advances in eye-tracking technology, the cost of commercial systems remains prohibitive. Even in the case of disabled users the number of disabled users who are able to afford such a system is a minuscule percentage of those that could stand to benefit from the technology. Eye-tracking is often not used simply because of the cost factor; making it a technology that is used only for niche applications.

Eye-tracking vendors complain that the lack of a killer application has kept the demand for the technology low and therefore, they have to charge the high prices in order to recover their R&D cost and remain in business. User's of eye-tracking complain that the high cost of eye-tracking systems limits the research on the use of eye-gaze in applications and interfaces. We are therefore caught in a vicious cycle of high cost and low demand.

The high cost of commercial systems ($5000 - $40,000) have led to numerous efforts to build home-brew eye-tracking systems as seen in [2], [4], [5], [6], [7] and [10]. However, building an eye-tracker and researching applications of eye-trackers are two very different tasks.

At the Eye Tracking Research and Applications Symposium held in San Diego in March 2006 the community backed the IPRIZE [7] – a 1 million dollar grand challenge for HCI which aims to achieve a ten-fold improvement in eye-tracking technology while at the same time making it affordable for the average person.

In this paper we examine the sources of high cost of eye-trackers and present ideas and approaches which can be taken to reduce the cost of eye-trackers and make them available to everyday users and especially to HCI researchers at an affordable cost.

## TECHNOLOGY BACKGROUND

Without going into too much detail, we provide a brief background on eye-tracking. Remote eye-tracking technology is a specialized application of computer vision. A camera is used to track the location of the center of the pupil with reference to the corneal reflection(s) of an infrared glint source. Since the surface cornea is nearly spherical, the position of the glint remains more or less fixed as the eye moves to focus on different points-of-regard (POR). Eye-tracking systems use the difference vector (P-CR) between the pupil position (P) and the corneal reflection (CR) to determine the gaze vector. Systems also need to be robust enough to accommodate head movement.

## COST FACTORS

We classify the costs associated with building a commercial mass-market eye-tracker into a) material costs (hardware), b) research and development costs (hardware and software) and c) business costs (manufacturing, marketing, sales and support). We argue that the latter two comprise the dominant factors in the cost of commercial eye-tracking systems.

### Material Costs

The hardware components of an eye-tracker include one or more high resolution, high frame-rate, infrared capable camera, camera lens, IR illumination circuitry and LEDs, and mechanical parts for housing and creating a fixed framed of reference. Since eye-tracking relies on tracking the corneal reflection, the camera resolution needs to be sufficiently high to get enough pixels on the eye region. It is possible to trade-off resolution for field-of-view by using a zoom lens that focuses on the eye however, this would severely limit free head movement. Current commercial systems rely on using cameras which have a 1-2 Megapixel resolution with a 50-60Hz. frame rate. These cameras are estimated to be in the range of $1,000-$2,000.

### Research and Development Costs

Reliable gaze-tracking requires the hardware and the software to work perfectly in concert. The hardware required for the IR illumination varied depending upon the approach used (dark pupil vs. light pupil). However, in either case, the hardware development is fairly straight forward and is explained in several papers. Including [2] and [9].

Developing and fine-tuning the software for reliable gaze tracking including calibration routines, APIs and software for analyzing gaze patters can take several person years of software development effort. Most commercial systems rely on custom developed image processing libraries and provide proprietary SDKs and APIs for developing applications using their eye-tracking systems.

### Business Costs

Given the current low demand for eye-gaze trackers, vendors spend a fair amount of their time and resources on marketing and sales. The specialized nature of current eye-tracking systems makes them suitable for use only by experts and as such cater to a limited market. Vendors are therefore forced to charge high prices on small volume (typically tens of unit on an annual basis) to get a return on their investment. The high price of the systems in turns makes it a high-touch sales process which requires vendors to have an expensive sales force which needs to travel and do in person demos before they are able to close sales.

In addition, systems are usually not robust enough to operate under all conditions, creating the need for hands-on customer support.

The combination of technological issues (hardware and software development) and market/business issues result in eye-tracking continuing as a boutique industry.

## TECHNOLOGY TRENDS

However, there is hope on the horizon. Higher resolution and higher frame rate cameras are becoming available at extremely low prices. The advent of cell phone cameras and low cost web cameras has made image sensors a commodity item which can be sourced incredibly cheaply. In addition the proliferation of USB 2.0 now provides adequate bus bandwidth to capture high resolution images at high frame rates. Moore’s law has made available sufficient processing power to be able to perform complex image processing in real-time and still leave enough cycles for other applications.The cost of image processing thereby becomes a smaller proportion of the CPU over time.

## COST-LOWERING APPROACHES

We present a series of ideas and approaches that may be used to lower the cost of eye-tracking systems.

### Use COTS cameras

Using commercial-over-the-shelf cameras is the obvious cost-cutting approach for reducing the material costs for eye-trackers. Megapixel resolution webcameras are now available for a fraction of the cost of the expensive custom cameras used in machine vision applications. The cameras use standard USB/Firewire interfaces, thereby eliminating the need for any special hardware/software drivers for image acquisition.

Commercial web cameras come equipped with an IR filter which prevents them from working in the IR spectrum. In addition, since COTS cameras are mostly color, the presence of the Bayer pattern on the CCD also reduces the effective resolution of the camera.

It is however, possible to perform minor modifications on commercial webcams to make them work in the IR spectrum and we have done so successfully by a) removing the IR filter and b) adding a visible light filter (Wratten 87).

Given the cost of COTS cameras it is conceivable that it is possible to have a grayscale IR sensitive sensor mass-produced at very low costs.

### Multiple cameras

Desktop Eye-tracking systems suffer from the limited field-of-view of the camera. As explained earlier, the image of the eye-region must be sufficiently zoomed in order to provide enough pixels for processing. We notice that in most desktop use scenarios the majority of head motion occurs in the horizontal plane. Therefore, it is possible to use a multi-camera (stereo) setup with a fixed geometry to increase the horizontal field of view without sacrificing resolution. In addition, stereo cameras can provide a mode accurate depth estimate and account for a wider range of head movement including head rotation.

It is our expectation that current systems would be limited to using a stereo setup (2 cameras) due to bus bandwidth and processing limitations.

Figure 1: The low-cost prototype in development uses commercial-over-the-shelf cameras modified to work in the infrared spectrum. The glint source pictured above uses IR LEDs (invisible to the human eye).

### Build on existing Image Processing Libraries

To control the cost of software development, it is possible to build eye-tracking software on top of existing Computer Vision and image processing libraries such as OpenCV. The openEyes [ ] project uses OpenCV as its foundation.

## LOW-COST PROTOTYPE

In order to test some of the ideas above we endeavored to build our own low cost prototype. We used the Logitech QuickCam Pro 4000 camera and modified the camera to work in the infrared spectrum as described before. Figure 1 shows an image of the modified cameras and the infrared glint source used for prototyping.

We were successfully able to capture both streams and verify the feasibility of a multi camera solution using a regular desktop PC.

We prototyped the GazeTracker software using the open source OpenCV library. The software uses the HaarFaceDetector in OpenCV to indentify faces in the captured image. To find eye-regions, we trained a classifier set using over 3000 sample eye images. Once the HaarFaceDetector has found a face within the captured image, the eye-models are used to isolate eye-regions. Simple erosion, dilation followed by ellipse fitting makes it possible to determine the location of the pupil center (P) and the corneal reflection (CR) which may then be used to estimate the point of regard.

## A MASS-MARKET STRATEGY

The primary impediment to mass-market low-cost eye-tracking is not the technology but the business issues relating to the supply and demand characteristics of eye-trackers. Therefore, no amount of technological innovation alone will be able to solve this problem. It is necessary to innovate and be creative on the business model used by current eye-tracking vendors.

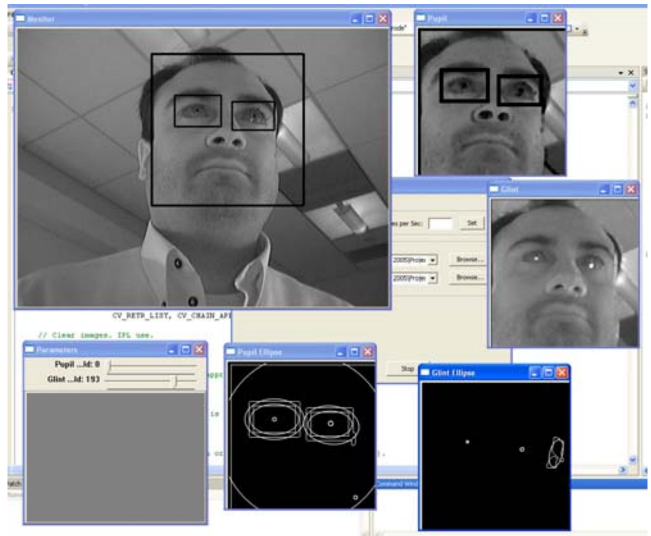

Figure 2: A screenshot of prototype software built using open source Computer Vision libraries (OpenCV) which uses machine learning to identify faces in the image. It then looks within the face region to identify the eyes. Simple image processing (erosion/dilation) helps to separate the pupil and glint images. Ellipse-fitting provides the center of the pupil and the glint which can then be used to determine the point-of-regard.

While we recognize that it is important for vendors to charge high prices for their eye-trackers to recover their R&D cost, we also feel that it is necessary for vendors to begin thinking about a mass market strategy and begin a process of gradually lowering the prices for their systems such that while they can maintain short term profitability, they also begin to grow the size of the market for eye-tracking.

## CONCLUSION

In this paper we discussed the factors contributing the to high cost of eye-tracking systems and proposed ideas that may help to reduce the cost of these systems. While this paper does not present a scientific evaluation of the proposed ideas and mass market business strategy, we do hope to encourage a dialog amongst members of the community.

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