# Do-It-Yourself Eye Tracker: Impact of the Viewing Angle on the Eye Tracking Accuracy

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## Abstract

In the paper we research the relations between the eye tracker accuracy and the human view angle. We measure the accuracy of the gaze point estimation for a typical and wide view angles and discuss limits of the field of view covered by an eye tracker. The measurements are captured during perceptual experiments with human observers. We built eye tracking station consists of our own construction eye tracking glasses and ITU Gaze Tracker software. It's based on the pupil-detection technique. We used this eye tracker station, called Do-It-Yourself, in the experimental hardware setup. We conduct perceptual experiments to measure eye tracker accuracy for increasing view angles.

**Keywords:** eye tracking,eye tracker hardware,view angle estimation,subjective experiments

## 1 Introduction

Eye tracking devices determine the position of the eye in space and compute position of a gaze point and a gaze direction. This information is utilised in science and technology, e.g. to test peoples' preferences concerning advertisement, or to control computer via the eye tracker interface, etc.

The progress in technology increases availability of computer monitors with large diagonals. They cover wider viewing angle and strengthen impression of the visualisation realism. Most probably, we can expect a display that covers the whole 180° degrees of human visual angle in the near future. The eye tracking technology must be adjusted to these parameters. However, other limitations of Human Visual System (HVS), like foveal vision, also influence the eye tracker operation.

The main objective of the article is determine a relationship between eye tracking accuracy and visual angle. We measure accuracy of eye tracker for small and large view angles. In research we used Do-It-Yourself (DIY) eye tracker: our own construction eye tracking glasses in cooperation with ITU Gaze Tracker software. We built this low cost eye tracker to gain full control over the eye tracking pipeline. We conduct perceptual experiments to measure eye tracker accuracy for increasing view angles. We determine the limits of accuracy resulting from eye tracker hardware design and possibilities of gaze estimation algorithms.

Section 2 presents basic terminology and classification of eye tracking techniques. Design of DIY eye tracker is depicted in Section 3. Section 4 contain the eye tracker accuracy concept. Section 5 described experimental procedure together with the discussion of results. We conclude the paper in Section 6.

## 2 Background and previous works

The tracking of viewing direction have been known in science for many years. With eye tracking techniques we are able to identify the place which a user is looking at. This discipline deals with the measurement, recording and analysing data about the location and movements of the eyeballs. The results of the eye tracker work is the point of regard. A subset of the points of regard is known as an region of interest (ROI). Science knows eye tracking analog methods for example contact lenses [13] or electrooculogram [1]. These methods are invasive and come into a strong interaction with the user. Modern eye tracking systems use the image of eye obtained by video equipment to calculate the point of regard. They are more comfortable for users than the intrusive methods. We distinguish two types of video based eye-tracking systems [6, 5]: mobile - the camera is mounted on the head and remote - the camera is located near the monitor. The mobile system consists of glasses or a helmet with mounted cameras that record the movements of an eye or eyes.Remote system consists of a camera located close to the monitor in the front of observer.

Eye tracking systems work in visible light [10] or in infrared light, based on the image of one eye [15] or stereoscopic vision [4].The infra-red eye apparition allows to locate the dark pupil, the bright pupil and the corneal reflection (See Fig. 1). [6]

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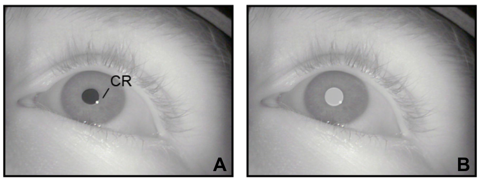


Figure 1: Appearance of human eye in infrared light: A) dark pupil and corneal reflection - a flash located on the surface of the eye, B) bright pupil.

The changes analysis of the vector connecting the centre of the pupil and corneal reflection is a classic example of the remote eye tracking method. Assuming that the eye is a sphere and rotates around its own centre and camera with infrared source is stationary then a corneal reflection position is unchanged to different gaze direction. The Corneal reflection can be used as a reference point. The centre of the pupil (or iris) with a corneal reflection create a vector which is mapped to the coordinates of the screen during the calibration process. This solution is non-invasive and allows user for small head movements. [12]. The remote methods divide into: based on changes of the pupil - eye corner vector [19], mapping of four corneal reflections [17, 18, 7] and based on the three-dimensional model of the eye [15].

Tracking pupil centre is a method which is used in mobile eye trackers (mounted on the head). It uses dark pupil, thresholding and model fitting method. The position of pupil centre is compensated with parameters derived in the calibration process. The result is an estimated point of gaze [11, 16]. The algorithms which works in the visible light use the centre of the iris to calculate point of regard.

The mobile eye tracking systems are less comfortable for user than the remote systems because some device must be wear. However, they range is not limited to display screen space and they can operate e.g. in the real environment.

## 3 Do-it-yourself Eye Tracker

In our project was created Do-it-yourself Eye Tracker station (DIY ET). The main goal of the project was to create inexpensive and simply in construction eye tracking tool. DIY ET base on self constructed eye gaze tracking glasses supported by open source eye tracking application.

### 3.1 Eye tracking glasses

DIY ET belongs to the group of head mounted eye trackers. It works in infra-red spectrum using dark pupil effects. The point of gaze is calculated by the position of pupil centre.

DIY ET consists of two main parts: eye tracking glasses and computer with ITU Gaze Tracker software. The construction of the eye gaze tracking glasses was based on articles [14, 3, 9].The glasses are made of off-the-shelf component. The main part of glasses is the capture module (Fig. 3D). It is responsible for providing an image of the eye to the computer. This module was created by using the Microsoft LifeCam VX-1000. We mounted a suitable filter in camera lens that allows capturing images in infrared light (Fig. 3A-B). The glasses are connected to a computer via USB port. Based on the USB technical specification a infra-red illumination system was integrated with the capture module. The infra-red LEDs are located on the capture module and supplied by USB cable (Fig. 3C). This solution is very practical. The capture module was placed at the end of the aluminium wire and then mounted to the modified safety glasses frame (Fig. 4).

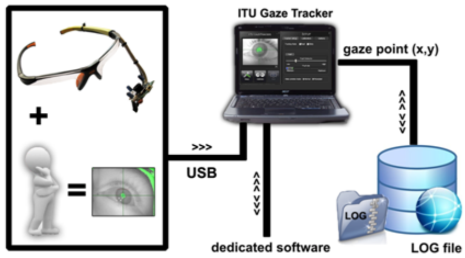


Figure 2: DIY Eye Tracking setup.

The created glasses provide a picture of an eye to the computer by USB. Then supported application computes the point of gaze and returns in the form of coordinates (X,Y). The coordinates are stored in LOG file or transferred directly to another application via client-server.

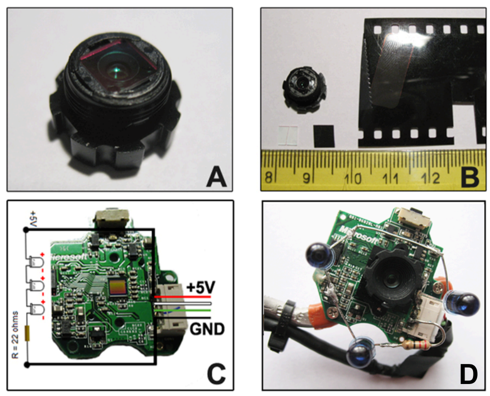


Figure 3: The creation of capture module: A) original lens from Microsoft VX-1000 web cam with visible light filter, B) preparation of IR filter, C) LEDs wiring diagram, D) capture module of eye tracking glasses.

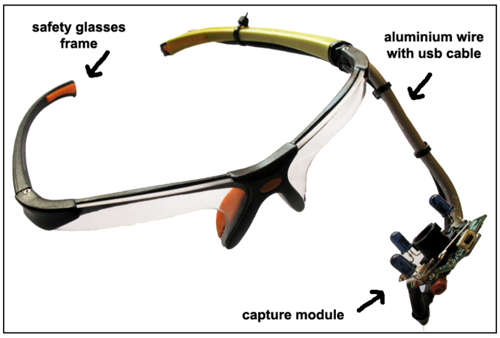


Figure 4: DIY eye tracking glasses.

### 3.2 ITU Gaze Tracker

The DIY eye tracker is controlled by the ITU Gaze Tracker software. ITU Gaze Tracker [2] is application designed in IT University of Copenhagen with open source licence [1]. The application estimates the gaze point by mapping the centre of the pupil to screen coordinates using the parameters obtained in the calibration process. Image of eye in infrared light is captured in consecutive frames. The pupil centre is determined and its movements are being tracked.

## 4 Evaluation of eye tracker accuracy

We discuss accuracy of eye tracking systems. The eye tracker accuracy is measured in degrees of visual angle.

### 4.1 Human field of view

The whole human viewing angle is about 180° horizontally and 130° vertically. However, the binocular field of vision covers only about 120° horizontally. Additionally, The details can be read only by fovea - a part of the eye located in the middle of the macula on the retina. Fovea extends from 1° to 5° the human view angle.

An eye tracker should operate in a view field that do not force head movements. One assumes that it is not more than 120° of binocular vision. For observer sitting in 50 cm distance from a screen, a display should be up to 170 cm wide.

### 4.2 Gaze angle

During calibration an observer is asked to look at a set of target points displayed in different position on the screen. The image of the eye is recorded and the eye pupil centre location is calculated. Correlation between calculated position of the pupil centre and known position of the target points is used to approximate coefficient $a_{0-5}$ and $b_{0-5}$ of the polynomial:

$$\begin{cases} screen_x = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2 \\ screen_y = b_0 + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2, \end{cases} \quad (1)$$

where $(screen_x, screen_y)$ are the gaze point coordinates on the screen, $(x, y)$ are the coordinates of the centre of the pupil [2]. The accuracy of calibration process significantly affects error arising during eye tracker operation. This accuracy of eye tracker is determined by indicating the differences in position between the reference points with known position and measure gaze points. The accuracy is expressed in degrees of visual angle.

### 4.3 Error factors affecting accuracy of eye tracker

A significant error affecting the accuracy of the gaze point estimation is the head movement. We use a chin-rest to stabilise the head and increase the DIY eye tracker accuracy. Other solutions utilise algorithms that compensate head movements [8] or use additional the head trackers.

For the wide view angles the eye tracker cannot detect pupil centre accurately. The extreme situation is presented in Figure 5B where pupil was not detected by image processing software.

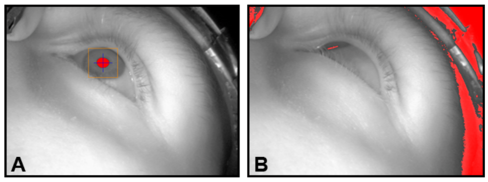


Figure 5: Detection of the pupil for standard (A) and wide view angle (B).

The DIY eye tracker is equipped in one camera and takes image of only one eye. The measurement error cannot be compensated by the data from the second eye. Another sources of errors encompass inaccuracies of the pupil centre extraction, variation of lighting and of shadows covering the eye. Changing illumination cause confusion in getting clear image of eye. For this reason the software cannot measure position of pupil centre. It is really important to provide stable lighting during research.

Results of DIY ET have a high standard deviation. It is characteristic for the data from the eye tracker and arises from the physiology vision of the human eye. Human eye fix independent of human will around gaze point. It can creates a outliers. Filtering the outliers may be the solution to reducing standard deviation.

## 5 Perception study

The goal of the tests was to find relation between the accuracy of eye tracker and an observer view angle. During tests we used hardware setup based on the DIY eye tracker.

[1] http://www.gazegroup.org/

### 5.1 Hardware setup

Our experimental setup is presented in Figure 6. It consists of the DIY eye tracker controlled by the ITU Gaze Tracker software (2.0 of this software). The application was activated on PC equipped with Windows XP SP3 operating system, AMD Athlon 64 X2 Dual Core Processor 3600+, NVIDIA GeForce 7600 GS 512MB graphics card and 3GB DDR2 RAM. The target points were displayed on Samsung SyncMaster 2233sn with the screen dimensions 46.5 x 27 cm, and native resolution 1920x1080 pixels (60Hz).

We used the chin-rest adopted from the ophthalmic slit lamp. The tests were conducted for three distances from eyes to the screen: 70 cm, 50 cm and 30 cm. Reduction of distance corresponds to increase an angle of view.

We used our own construction eye tracking glasses (Fig. 4). The glasses worked with 640x480 pixels resolution and 30 fps frequency.

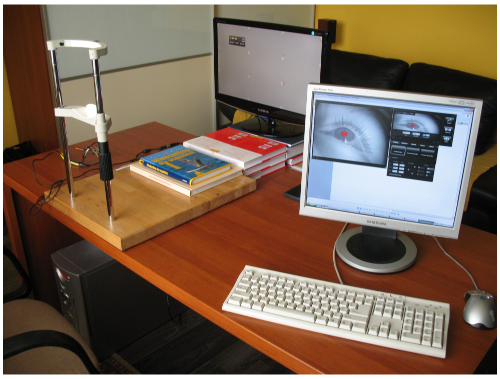

Figure 6: Hardware setup used during experiments.

### 5.2 Participants

Ten users with an age from 21 to 56 participated in our experiment (two woman's and eight men). Seven participants had normal vision, three of them had corrected vision with lens. We asked each participant to repeated the experiment three times for each distance. In all we have ninety measurements, thirty for each distance. The whole experiment for one person lasted less than 8 minutes. Participants were aware that accuracy of the eye tracker is tested, however they do not know details of the experiment.

### 5.3 Procedure

The participants were asked to wear the DIY eye tracker and use the chin-rest to stabilise the head. They looked at the target points that were displayed on the screen one by one in random order as white circles. The procedure was repeated for 70 cm, 50 cm and 30 cm distances by tuning position of the monitor. The monitor and participant were located on the same axis of symmetry.

### 5.4 Results

Figure 8 presents all data collected during the test procedure. Location of the target points is marked by red circle, the observers' gaze points are depicted as a blue dots. Distribution of gaze points for shortest distance (highest view angles) is more spread out and does not follow the target point position very well. It results higher accuracy error. Figure 7 presents box plots of average error for sixteen target points. The central mark (red line) indicates median value of the error, the edges of the box are the $25th$ and $75th$ percentiles, the whiskers extend to the most extreme data points not considered outliers. Outliers are plotted individually as red crosses. The blue horizontal line indicates view angle error equal to one degree of visual angle.

For $70cm$ distance from screen, average error for all target points amounts to $0.34deg$ (with standard deviation equal to $0.49deg$) for horizontal direction and $0.45deg$ (with standard deviation equal to $0.58deg$) for vertical direction. For higher view angles ($50cm$ distance), the errors increase to $0.59deg$ (standard deviation $0.75deg$) and $0.55deg$ (standard deviation $0.59deg$) for horizontal and vertical direction respectively. For highest view angles ($30cm$ distance), the errors increase to $1.77deg$ (standard deviation $1.71deg$) horizontally and $1.20deg$ (standard deviation $1.03deg$) vertically.

The results of our experiment demonstrated high influence of observers' viewing angle on eye tracker accuracy. The best accuracy was measured for largest distance from screen (70 cm). Precision dropped with reduce the distance and is worst for 30 cm (widest angle of view). However, we did not notice this relationship for the individual target points.

There are no regular fluctuations of the error for central and extreme target points. In Fig. 8-bottom we observed dependence between four centre points and rest outside points. The gaze points for the centre reference points have got worse accuracy than the outside gaze points. They are strong shifted toward outside. It is not expected dependence because these four centre points are placed in sharp field of view (for 30 cm distance) contrast to the outside points. Large group of outside points (12 points) affect to calculation of polynomial terms stronger than group of centre points (4 points). In this case the outside points have got better accuracy than the centre gaze points. This error is consequent of calibration method implemented in the ITU Gaze Tracker application.

## 6 Conclusions and future work

The main contribution of this paper is indication relation between accuracy of eye tracking system and viewing angle. Precision drops with wider angles of view. Accuracy of the DIY eye tracker is close to 0.6 degree for standard viewing angles (up to 30 degrees, 50 cm distance from screen). It is satisfactory result considering low cost of the eye tracker. However, the accuracy decreases to 1.7 degrees for wide view angles what seems to be unacceptable in most applications.

In future work we plan to implement validation of DIY eye tracker which allows to achieve more accurate results and shows better the relationship between the eye tracker and the wide angle. Combination of eye tracking with head tracking seems to be the solution of head movements problem. We plan to build low cost head tracking device and integrate it with the DIY eye tracker.

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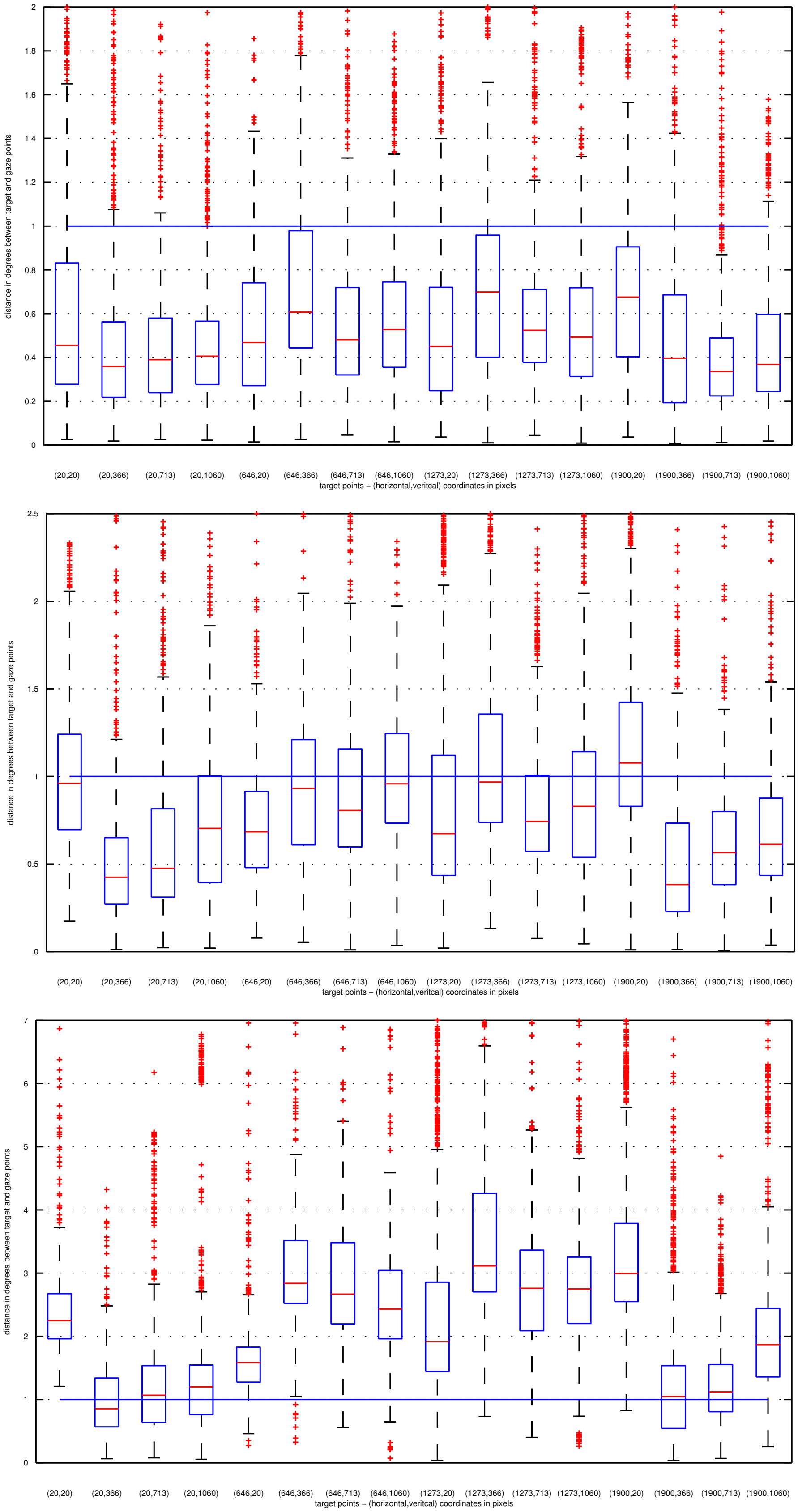


Figure 7: Average distance between target and gaze points in degrees of view angle for 16 target directions. Observers' eyes located 70 cm (top), 50 cm (middle) and 30 cm (bottom) from the screen.

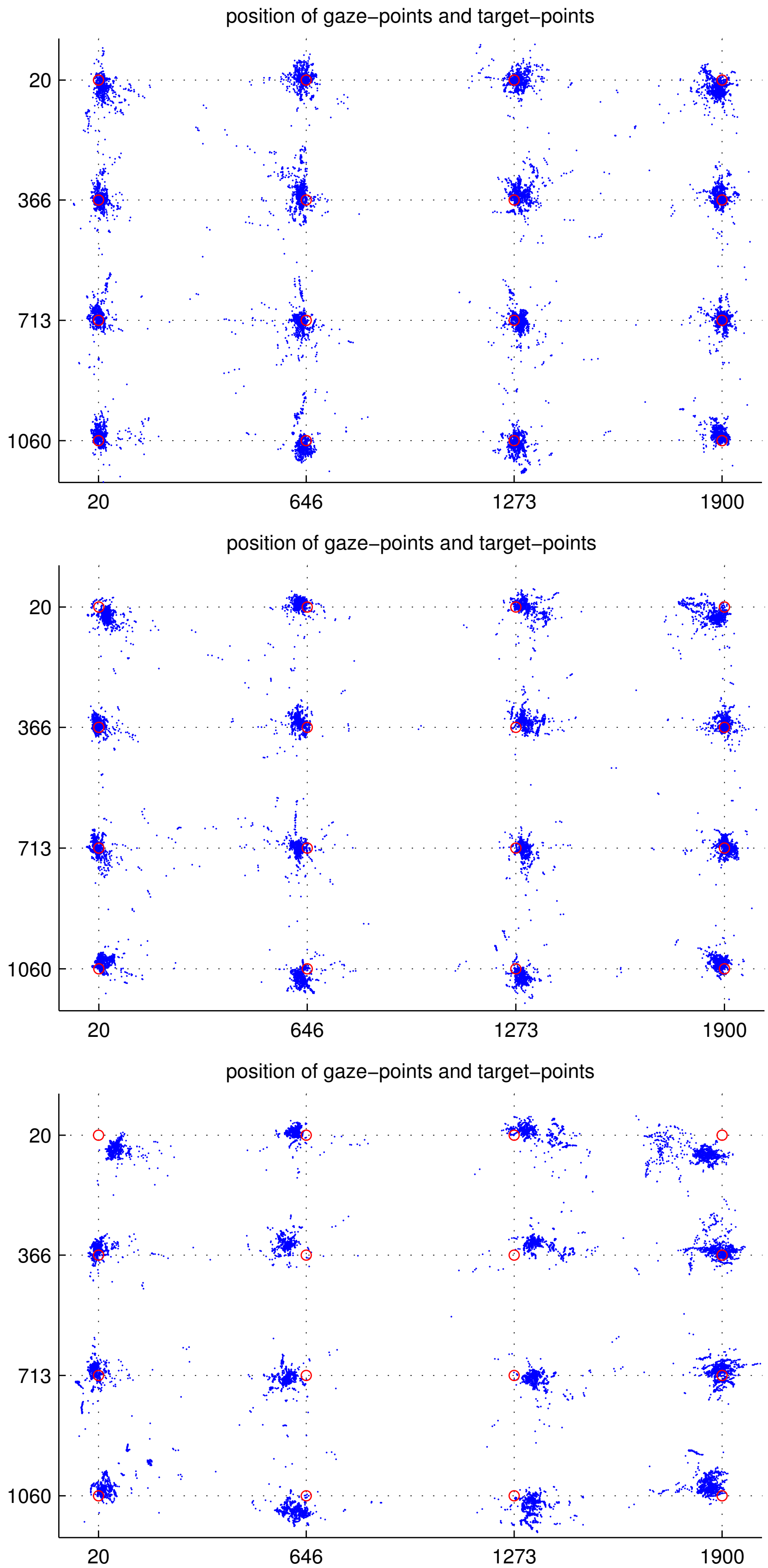


Figure 8: Position of the target-points (red circles) and measured gaze-points (blue dots). Observers' eyes located 70 cm (top), 50 cm (middle) and 30 cm (bottom) from the screen. Point positions in pixels.