How Not to Become a Buffoon in Front of a Shop Window: A Solution Allowing Natural Head Movement for Interaction with a Public Display

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Abstract. The user interaction solution described in this paper was developed in the context of an Intelligent Shop Window (ISW) with an aim to offer a user the interaction solution where system response would be triggered by naturally gazing at products. We have analyzed a possibility to realize such a user interaction solution using gaze tracking and concluded that remote calibration free eye tracking is still a subject of academic research, but that head tracking could be used instead. We argue that conventional use of head tracking requires conscious intentional head movements and thus does not fit into the context of applications such as the ISW. We further describe our experiment aimed to explore how head movements relate to eye movements when looking at objects in a shop window context. We show large variability in head movement and that per individual the gaze-head data could well be approximated with a straight line. Based on these results we propose a new solution that enables natural gaze interaction by means of head tracking.

Keywords: Gaze Interaction, Head Tracking, Augmented Reality Systems.

1 Introduction

Our current work originated from an exploration of new innovative interactive solutions for physical retail stores. In the last decade retail has undergone a significant transformation fuelled by the competition with on-line shops [1]. Retail brands grew into a blend of the old brick and mortar stores complemented by on-line services. This trend is also reflected in a shift towards experience, entertainment and themed retail, with the most known examples of NikeTown, and flagship stores of Apple, Nokia, and Prada. Physical retail was forced to appeal to shoppers in new ways to please the shopping motivations of modern consumers. In order to attract new customers to their shopping spaces retail frontrunners turn to different forms of interactive technologies. One that has been recently adopted by a number of leading stores is an interactive shop window display. These are interactive displays ranging from flat panel LCDs to holographic foil based rear projection screens [2, 3] integrated with a touch sensor like a capacitive touch screen [4] or an infrared optical sensor [5]. Leading brands like Ralph Lauren and Toyota have installed interactive shop window displays in their stores to make their shops accessible 24 hours a day [6, 7].

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To construct an elaborate view on the shop window context we conducted field studies in three downtown shopping centers and two shopping malls in Europe and United States. During these studies we observed and interviewed shoppers and retailers in order to understand the shop window from diverse standpoints. One of the results shows that the time most people spend at the shop window during shopping hours is very short and it varies from a short glance for duration of a second to a short stop for a minute or two. This time is too short to start browsing intricate information such as an electronic catalogue on the shop window. It has been demonstrated that due to the fact that public interactive displays are open to every onlooker it generally discourages people from trying to use them out of fear of doing something wrong or because it makes them look stupid [8]. One way to deal with both aspects of the shop window context mentioned above, is to use implicit interaction rather than explicit. Implicit interaction is one of the facets of augmented reality systems where the system can automatically trigger a particular reaction just by sensing and reasoning about user behavior. The advantage is that the user does not require any prior knowledge or training in order to interact with the system since no explicit intentional control actions are needed [9-11].

From the field studies we learned that the shop window is a visiting card of a shop designed to attract the right customers. That is why product items exhibited in the shop window are carefully selected eye-catchers that stand out from the rest of the assortment due to their novelty or originality. This motivated us to relate the content offered on the shop window display to the physical products exhibited inside the shop window. In our observation studies we, among other aspects, have observed how people attend to shop windows. Although we spotted people pointing at products, discussing products among each other and waiting for a partner at the shop window, mostly we saw people simply looking at products in the shop window. This triggered us to explore a possibility of detecting which product people look at in the shop window in order to implicitly trigger an interactive experience related to that product. We next describe the implemented concept where we have explored the possibilities offered by gaze interaction to shoppers at a shop window.

1.1 The Intelligent Shop Window Demonstrator

To explore the feasibility of the gaze interaction concept we have realized the demonstrator of the ISW in the shop area of our experimental facility. The shop area is part of a larger activity dedicated to realizing new innovations for retail and it is built to resemble a high end fashion store. In the ISW demonstrator, the shop window display is realized by using a holographic projection foil (i.e. Holo Screen [2]) that creates a semi-transparent display. Such display enables the user to shift easily the focus of visual attention between the products and the display (Figure 1). In the figure it is shown that a user is interacting with the shop window using touch based interaction. The window on the right is used for gaze interaction, where users can trigger selection of products with gaze. Details of how this is done are described next.

To build the gaze based implicit interaction for the shop window we needed a remote user independent gaze-tracker. The dilemma is that most commercially available gaze trackers are made for desktop use and thus operate on a short distance of about 60 cm. These systems require calibration and have poor tolerance to head motion.

Fig. 1. The Intelligent Shop Window (ISW) demonstrator in Philips Research Eindhoven

Remote user independent gaze tracking is the cutting edge of gaze interaction research with two main challenges: to eliminate the need of calibration per user and tolerate head motion [12-14]. Most advanced remote trackers do require a per-user calibration and only a few calibration free gaze trackers [15-18] have been shown to work in laboratory conditions but never in the field.

To start experimenting with gaze interaction in the context of the ISW we have acquired the Smart Eye 4-camera set-up [19] capable of detecting both head and eye gaze vectors. Smart Eye requires a calibration profile per user which is created by marking at least 12 feature points in at least 12 snapshots. Having installed the Smart Eye as part of the ISW we considerably stretched the boundaries of what the system could possibly deal with. In our set-up the cameras are placed behind the shop window and as a result there is a glass panel and a Holo Screen panel between the face of the user and the cameras. Part of the projected image reflects back into the cameras and could distort the tracking. Large distances between the person and the cameras of about 1.25m resulted in just a few pixels left for the pupil region in the image. Due to these difficulties, we could only achieve robust head tracking but not eye tracking. The experience with the Smart Eye triggered a question whether head tracking alone could be sufficient for a public interactive display such as the ISW.

Contrary to the challenges already mentioned for remote eye tracking, remote user independent head tracking is an affordable technology that has even been demonstrated in the context of interactive public displays [20-22]. These particular solutions focus primarily on the detection technology itself and not on its usability. In [20, 21, 23] head tracking is used in an explicit way, alike its traditional use in the field of assistive computing, i.e. head mice [24]. When head tracking is used in an explicit way the user needs to intentionally move her head in order to interact with the system. This is well accepted and even preferred in certain contexts [24], however, in a public context of a shop window people might feel that it is odd or unnatural to do due to the psychological barriers mentioned earlier [8]. Consequently, we defined our aim as to establish how head tracking could be used in an implicit way for interaction with the

ISW. To achieve this we had to figure out how head movements would relate to change of gaze in the context typical for a shop window. Therefore as an integral part of our paper we describe next the experiment that was carried out to determine the relationship between head and eye movements and the quantitative results that were found. Lastly we contemplate regarding the interaction solution that emerged from our results, which offers the tracking of gaze by employing head movement only.

2 Head Movement Experiment

2.1 Literature Overview and Our Approach

It has been widely accepted in literature that beyond a threshold of an angular viewing distance of 40 degrees head movements are mandatory [25, 26]. It has also been demonstrated that people develop different strategies as to what extent they involve head movement when looking at targets within the 40 degrees frontal view, which is referred to as head movement propensity [25]. All studies we reviewed demonstrated a large variability with respect to the head movement propensity. These differences gave birth to the classification of people as head movers and non-head movers. In [26] head movement was investigated for subjects whose head was free and a semicircular array of LEDs spaced 1 degree apart within a range of ±50 degrees was used to generate stimuli, e.g. illuminated LEDs. Again a great variability of head movement propensity was observed. This study reports an eye only region, which is a range of target eccentricities where head movement was not evoked by head non-movers. This region was observed to lie approximately within a range of ±20 degrees in the frontal view. It was revealed that outside the eye only region head movement linearly related to the amplitude of gaze shifts. Several studies [26-28] demonstrated an almost proportional relationship between gaze and head shifts within the ±20 degrees frontal view for head movers. It has been shown that the relationship between head movement and eye movement is influenced by experimental conditions [25, 26]. Therefore, we could not simply rely upon the results of the previous studies and had to experimentally show how head movements relate to gaze shifts in the context of the ISW.

Previous studies used very simple visual stimuli (i.e. lights) that suited the goals of their research [25, 26, 28] but it was disputable whether their results would hold in the context of the ISW. Our hypothesis was that the size and content of the target would have a bearing on how much head movement is carried out. As a result in our experiment we manipulated both product type and the size of the product. All the studies we found on head movement did not vary the distance between the user and the stimuli. Therefore we also included viewing distance as one of our independent variables. It was reported in head movement literature that vertical head movements have a smaller range than those of horizontal [29]. We did not find any estimate of that difference and therefore in our experimental design both horizontal and vertical conditions were included as independent variables.

2.2 Determining the Accuracy of the Smart Eye Tracking Device

Smart Eye claims a head pose accuracy (gaze vector originating from the nose in 3D) of a rotation of 0.5 degrees and a translation of 1 mm square [19]. In the context of the ISW, Smart Eye had to deal with challenging conditions, such as the glass and holographic foil, therefore it was imperative to estimate the precision of the Smart Eye in order to show whether it would be sufficient for the main experiment. In order to estimate the accuracy, we mounted an artificial head upon a movable tripod. A disk with an angular scale was mounted on top of the tripod and it allowed for up to one degree of radial movement. We also used a white sheet with equidistant targets marked upon it. In order to accurately orient the artificial head towards the targets, a laser pointer was attached on the top of the head, so that the laser beam would be parallel with the head orientation vector. The head could be moved vertically via adjusting the height of the tripod and horizontally by rotating it on top of the disk. Moreover, the artificial head was calibrated for the Smart Eye. We recorded Head Heading and Head Pitch generated by the Smart Eye tracking device. For each target we ensured the laser was aimed at that target and after the tripod and the disk were locked, data was recorded for 20 seconds. We performed the analysis of the data by computing an error distribution for each target. The error distribution was given by a distance matrix for each pose, which summarized the error differences. The analysis was based on the assumption that given that the head was not moving the readings would indicate no change over time. By normalizing the error distribution with a Gaussian function, we came to the conclusion that the Smart Eye had a precision error concentrated within 3 degrees. Hence we concluded that the precision of Smart Eye was acceptable to be used for the main experiment.

2.3 Method

Design. The aim of the experiment was to explore the relation between head movement and gaze changes, such that given head movement we could determine an approximation of the gaze. We recorded measurements for horizontal and vertical head movements (movement type) for different angular distances between the targets (angular distance), varied the distance between the subjects and the targets (viewing distance) and manipulated the size and the content of the targets (image type). The experiment was setup as a movement type (2) between subjects × screen viewing distance (3) × image type (3) × angular distance (5) within subjects design.

Participants. We recruited 21 participants in total. The gender profile and the allocation to the horizontal and vertical conditions are shown in Table 1.

Table 1. Number of participants per condition

	Participants	
	Male	**Female**
Horizontal	6	6
Vertical	5	4

Procedure. Participants were presented with a pair of targets simultaneously in the middle of a screen mounted inside the shop window. In order to notify the participants where to look first a counter was shown on the screen before the targets would appear. The counter appeared either on the left or the right of the screen (in the case of the horizontal condition), or on the top or the bottom (in the case of the vertical condition) along the center and it was placed at the position of the first target.

After displaying the counter, 3 intermittently appearing digits accompanied with 3 audio beeps, the counter would disappear and the two targets, T1 and T2, would appear simultaneously on the screen. We instructed the participants to look initially at the first target that would appear at the location of the counter and then at the second target (T2). The participants were specifically instructed not to look back and forth. We explicitly did not give any details as to how to look at targets rather we asked to look at the targets in the way they would naturally do. Both T1 and T2 were identical images of a particular object. The sequence of presentation of images was randomized in conjunction with the angular separation. Each pair of targets remained on the screen for 3 seconds. Between subsequent presentations of each pair of targets there was a gap of 5 seconds (2 seconds during which the screen was blank and the 3 seconds counter). The target presentation was repeated for a total of 3 (image type) X 5 (angular distance) X 6 (trials) = 90 times per each screen viewing distance. A typical experimental session with every participant lasted for slightly more than an hour.

In studies related to gaze interaction, time provided for fixation is an important factor. Fixation measurements in time normally for a scene with two targets or objects would consist of: the initial fixation on the first target (on average 750 ms); a scan time, being gaze shift from first target to first entry in the region of the next target (on average 100 ms); a final gaze fixation (on average 1000 ms) [30]. We had to be careful in allotting the time for each fixation, as it has been reported that longer fixations could encourage head movement [25]. We decided to increase slightly the window used to conduct fixation measurements up to 3 seconds, to ensure that all trials were successfully completed. The 3 second fixation period was confirmed in the pilot experiments. Each combination of within subject experimental variables (screen viewing distance, image type and angular distance) was tested in 6 trials. However, we manipulated the position of the counter in every set of 6 trials, such that for three trials the counter would appear in the left or top part of the screen and for the remaining three - in the right or bottom part, for the horizontal or vertical conditions accordingly. These left-right and top-down orientations of trials were randomized. Targets were presented in the centre of the screen with a distance separation that was computed upon the corresponding angular distance between the targets.

2.4 Materials

In order to display the stimuli a plasma screen (1.13 m by .65 m) was used which was suspended such that it was easily movable along a rail, hereby allowing us to manipulate its distance from the user. The position of every participant was measured prior to every viewing distance condition and the participants were instructed not to move during the condition (see Figure 2). The screen was mounted so that it would roughly lie in the center of the viewing fulcrum of a user standing in front of the ISW. For the vertical orientation condition, the same screen was rotated 90 degrees anticlockwise. All tracking was carried out by the Smart Eye device.

Fig. 2. Participants undergoing the experiment in both conditions: left-horizontal and right-vertical

2.5 Independent Variables

The image type factor had three levels conventionally coded as *small*, *medium* and *large*. *Small* corresponded to the image of an mp3 player, *medium* was the image of a perfume bottle and *large* - the image of a bag (see Figure 3). We used images of different products, instead of scaled versions of the same product to increase ecological validity and to prevent the participants from feeling bored or even withdraw from the experiment.

Fig. 3. Type of products: mp3 player, bottle and bag

The screen viewing distance factor was also defined according to the three levels: *small*, *medium* and *large*. The observation studies mentioned in the introduction provided an approximate estimate of typical viewing distances: 0.5m to view smaller products and 1.5m for larger products. Due to a restriction of our cameras set-up, we could not test the distance of 0.5 m. Therefore we tested the three distances of 1.0 m, 1.25 m, and 1.5 m for *small*, *medium* and *large* conditions respectively. The distance was measured from the centre of the feet of the participants to the display screen. In order to counter balance any effects of fatigue or boredom over the three viewing distances, the order of the presentation of the screen viewing distances was varied between subjects. In total we had 6 possible orders, where each order was executed for two participants, where possible. Between each of the three sessions, participants were able to take a break, while the viewing distance was adjusted.

From literature [26] we learned that a ±20 degrees window was identified as a so-called eye only region and head movements beyond this range would become mandatory. This range is also typical for viewing products in a shop window context. We chose the following five angular distances between images, expressed in degrees: 10, 15, 20, 25 and 30. Since we could not reliably track gaze with the Smart Eye we could only rely on our subjects shifting their gaze in a way that corresponded to the angular distances we had defined. To ensure this we carefully instructed the participants on the sequence they had to follow when looking at the targets.

2.6 Measurements

We carried out several pilot studies in order to test our experimental setup and check whether the data output corresponded to what we expected to happen. The Smart Eye outputs numerous parameters per frame. The most relevant parameters for our case were the angular direction of the head pose vector (expressed in radians) in both horizontal and vertical directions. They are termed as Head Heading and Head Pitch respectively. In order to convert the head angular measurements into head movement shifts we first plotted the Head Heading data as shown in Figure 4. As it can be seen there are three distinct regions. These three regions represent the fixations on the two targets (horizontal regions 1 and 3), and the transition between the two fixations (central region 2). In order to obtain the estimate of the head movement we were interested in the distance between the two horizontal parts of the curve.

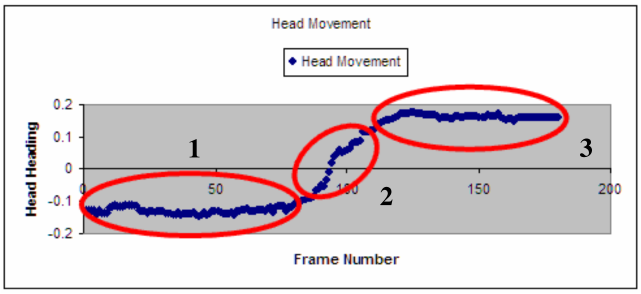

Fig. 4. Head Heading plot over a trial for a left to right head movement

To compute the head movement shifts, we used a simple k-means clustering algorithm, which was executed offline in MATLAB, after each experiment. By dividing the data of a trial into three clusters, we could subtract the centroids of the two most populated clusters to get the resulting head movement for each and every trial. The final value for head movement incurred for a particular combination of angular distance, image type and viewing distance was the median of the 6 trials. The median was used to account for outliers, if and when the tracking was not flawless.

3 Results

We shall present our results in a threefold manner. We evaluate the two between subject orientation conditions separately (horizontal and vertical) and conclude with a final comparison of both movement types. All statistical analysis was done on the median head movement values per each combination of independent variables.

3.1 Horizontal Head Movement: ANOVA Main Effects

The average horizontal head movement per participant across all the experimental conditions is visualized in Figure 5. Our first research question was whether the viewing distance, image type and the angular distance had an effect on the horizontal head movement. We performed a 3 by 3 by 5 repeated measures within-subjects analysis of variance (ANOVA) on the data from 12 subjects with gender and the screen viewing distance order as between subject factors. The repeated-measures ANOVA revealed significant difference in head movement for different angular distance conditions (F (4, 16) = 33.04, $p < .001$). The image type did not reveal a significant influence head movement (F (2, 8) = 1.63, $p < .26$). The same was true for the viewing distance (F (2, 8) = .863, $p < .46$). Surprisingly, gender appeared to have an effect (F (1, 4) = 10.88, $p < .03$). Females were observed to carry out almost twice as much horizontal head movement as males. Moreover, we found a significant interaction effect between gender and angular distance, (F (4, 16) = 5.06, $p < .008$). Screen viewing distance order did not have an effect (F (5, 4) = 4.315, $p < .09$).

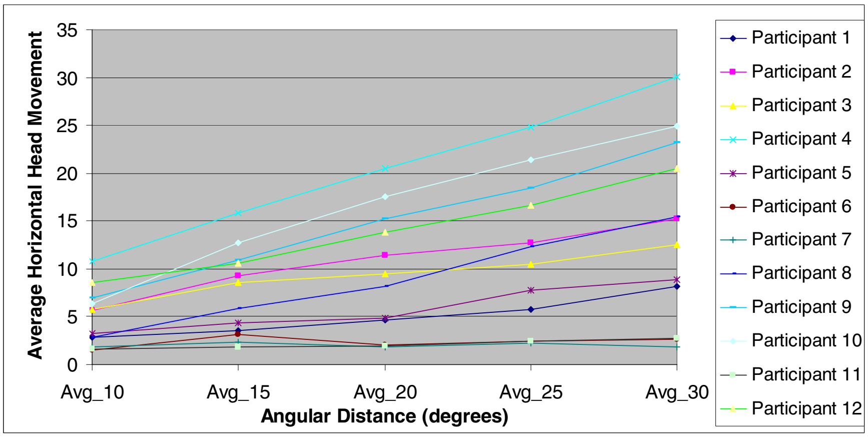

Fig. 5. Average horizontal head movement per participant

3.2 Vertical Head Movement: ANOVA Main Effects

The average vertical head movement per participant across all the experimental conditions is visualized in Figure 6. Similar to the horizontal movement condition we carried out a within-subjects repeated measures ANOVA. The results of the repeated-measures ANOVA turned out to be similar to the results that we had computed previously, for the horizontal movement condition. We found out that different angular distance conditions were significantly different with respect to the amount of vertical head movement (F (4, 28) = 5.69, $p < .002$). The screen viewing distance did not have a significant effect (F (2, 14) = .390, $p < .68$). No effect was found for image type (F (2, 14) = .12, $p < .89$) as well. However, contrary to our results for horizontal head movement, gender did not have a significant effect on vertical head movement (F (1, 7) = .011, $p < .92$). Screen viewing distance order did not show an effect either

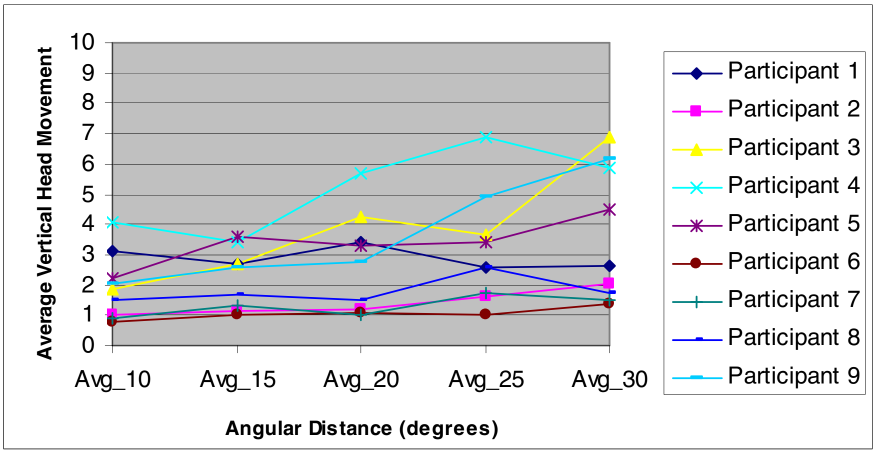

Fig. 6. Average vertical head movement per participant

(F (5, 1) = 25.14, $p < 0.150$). There was no interaction effect found for the vertical condition. Prior to conducting the experiment we suspected the height of a participant to have an effect on the vertical head movement. This was mainly due to the possibility that the starting point of fixation would vary from person to person due to the height, which could in turn influence the net vertical head movement carried out. Therefore the height of a user was also taken into consideration as a between subject factor in the ANOVA analysis. However, the ANOVA results did not reveal any significant effect of the height ($\underline{F}$ (1, 6) = .289, $\underline{p} < .61$).

3.3 Comparison between Horizontal and Vertical Head Movements

As stated previously, in earlier research it has been suggested that the vertical head movements has a relatively smaller range than the horizontal. We did not come across any studies that would quantitatively compare the two. In our experiment we collected head movement data in both horizontal and vertical conditions. To estimate the difference we compared the overall average head movement among the horizontal and vertical conditions. A two samples independent t-test was executed to compare the overall means for horizontal and vertical head movement conditions. The difference turned out to be significant ($\underline{t}$ (12.54) = 3.6, $\underline{p}$ = .003). Secondly, to estimate the relative difference we compared the median head movement in the horizontal condition (Mdn_H=9.13) with the median head movement in the vertical condition (Mdn_V=2.88). We concluded that the vertical head movement was on average 3.17 times less than the horizontal.

4 Discussion

In both horizontal and vertical conditions we did not observe any effect of the product type and the viewing distance on head movement. These results are important since previous studies did not investigate the effects of these two factors. For the shop window interactive applications these results mean that within the typical range of viewing distances head movement that accompanies natural gaze behavior is not effected by the distance towards the products or even by product type. With regard to the screen viewing distance we tested the range of distances typical for shop window situations (1, 1.25, 1.5 m) but the range could be different in other contexts. A limitation we had is that the smaller distance of 0.5 m could not be tested due to the physical arrangement of the apparatus. The viewing distance effect should be further investigated including the 0.5m distance.

In previous research it has been demonstrated that people could be categorized as head movers and head non-movers [28]. It has also been shown that any individual could be positioned on a continuum between extreme head movers and head non-movers [26]. Our results are in line with previous research and we observed a large variability in head movement propensity. Our results also show that both horizontal and vertical head movement had a positive increase for larger angular distances between products. Upon visualization of the results we showed that per individual data could be well approximated with a straight line. Similar linear dependency has been suggested previously in [26, 28] but was not investigated intricately.

Gender proved to be an interesting factor with regard to horizontal head movement. It is generally known that females demonstrate a larger variability for certain cognitive tasks that are experimentally related to natural hormonal changes. In contrast, gender has not been reported to influence head movement in earlier studies. One possibility could be that the content of the images or the context of the shop window was more appealing for females. Or it could be that the case that the gender effect was observed due to a small sample size. The gender effect needs a separate study to be verified. The results obtained triggered ideas for bringing them into practice for the ISW and next we provide a description of a new gaze interaction solution for the shop window.

5 User Interaction Solution

In line with previous research [25, 26, 28] we have observed a large variability in the head movement propensity (Figure 5 and Figure 6). It can be concluded that only a small fraction of people align their heads with their gaze targets. In other words in case of conventional head tracking as described in [20, 21], where head headings are translated into gaze headings identically for all users, the majority of people would have to intentionally exaggerate their head movement to be able to interact with such systems. In order to control such a system the user needs to be trained beforehand in order to understand how the system is controlled.

Another key result is that for every participant head movement observations for different angular target distances approximate well upon a straight line. To deduce this linear head-eye relationship it is sufficient to know at least one single head displacement between two widely spaced products. Using this single displacement and a priori statistics collected on head movement behavior it is possible to select the best fit line that most closely approximates the head movement of the individual. As we have demonstrated experimentally vertical head movement was on average 3.17 times less than horizontal. Therefore the vertical component for head movement can be calculated by simply dividing the horizontal by 3.17. Here we make an assumption that the amount of head movement for an individual is proportionally equal in both horizontal and vertical conditions. Since we tested the two movement types between subjects our afore-mentioned claim would need to be substantiated.

Ideally the proposed system calibration should occur in the background, hidden from the user. To achieve this we propose a method of attracting the user's attention to the targets in such a way that it would not be immediately obvious to the user. In visual perception it has been demonstrated that a dynamic visual effect on a static background is among the most suitable ways to attract human attention [31]. In our design we suggest to use a dynamic colored light effect to highlight one after the other two widely spaced products in a shop window. In this way the user's attention could be drawn first to the first product and then to the second product. In parallel to attracting the user's attention the system measures the corresponding head vector displacement and calculates the approximate gain factor for translating the head movement measurements into the gaze vector.

The interaction solution as described above enables natural and untrained interaction for public interactive displays where instructing users would neither be possible nor desirable. In case the user is aware that the system is controlled by head movement, the proposed interaction solution offers a benefit of deploying natural head movement without the need of intentional or exaggerated head movement.

6 Future Research and Conclusion

Currently we are in the process of implementing the described interaction solution as part of the ISW in order to be able to test the feasibility and usability in a laboratory setting. As we progress with our demonstrator we need to address a number of technical challenges. One of them is the difficulty the system will have with extreme head non-movers. It still needs to be determined what the minimum head movement angle should be in order to be sufficient for the system to distinguish between gazing at different targets. A gender effect that was observed should be definitely further investigated. Head movement gender differences might lead to new gaze interaction solutions for retail. The interaction solution as described above should be applicable to contexts beyond the ISW, e.g. product displays inside a shop, museum exhibition stands, and other public interactive displays. How our interaction solution would fit these new contexts needs further exploration.

In this study, we aimed to find a method to robustly estimate a user's gaze direction when she is looking at objects in a shopping window, without having to build a profile of the user's face in advance as is typically required for state of the art gaze trackers. User independent head tracking technology is already available, but it does not provide a gaze direction. To solve this dilemma, we explored the relation between head and gaze movement when viewing products of typical sizes at typical distances and at relative positions found in shop windows. For horizontal directions, we found that the amount of head movement for a given gaze shift differed greatly between participants. However, for each individual, the relation between head shifts and angular gaze shifts was found to be close to linear for the angular ranges studied

(10-30 degrees). No significant influence of object size or object distance was found. However, for the vertical direction head movements were about 3 times smaller than for horizontal movements. From these observations we derived a gaze tracking method, such that a user's gaze direction is estimated from her head movement. This interaction solution allows users to look at objects naturally, without the need to move the head intentionally which would exaggerate the movement amplitude.

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