Abstract—An automatic model is presented for animating gaze shifts of virtual characters towards target locations in a virtual environment. Two connected components are described: an eye-head controller and a blinking controller. The gaze control model is based on results from neuroscience, and dictates the contributions of the eyes and head to a gaze shift according to an individual's head movement propensity; that is, their tendency to recruit their head when making gaze motions under different conditions. The blink controller simulates gaze-evoked blinking, a specific category of behaviours that accompany gaze shifts. The probability of occurrence of such blinks, and their amplitude, is related to the gaze shift. These factors provide more believable gaze animations and allow for variety in animation. The model is of particular significance to serious game environments, where the control of a character's gaze behaviour may affect engagement, immersion and learning outcomes.

I. INTRODUCTION

Virtual characters form an integral part of applications featuring virtual environments, from computer entertainment titles to serious games. The purpose of such characters may merely be to contribute to the overall believability of scenes, by being visible as crowds of spectators in the background, or may be more active and prominent, by engaging in close-up interaction with the user, for example during pedagogical situations, as is the case with Embodied Conversational Agents (see, for example, Greta [1]).

Given the wide repertoire of behaviours that a virtual character must be capable of conducting, one of the most fundamental is the ability to attend to the user and environment in an appropriate manner by orienting the head and eyes to fix the line of sight. As noted in [2], many animals, including horses and rabbits, have eyes in the lateral areas of their heads, removing the need for them to substantially reorient their heads in order to change their line of sight. In contrast, human eyes are set into the front of the skull: given the anatomy of the eye, where highest acuity is constrained to a small area near the centre, gaze shifts are therefore a common component in the reorienting of one’s attention. Additionally, eye-gaze can be employed as a signaler of interpersonal attitudes and emotions. Its close relationship to the perception and visual attention mechanisms of the organism helps to allow adversaries and allies to infer internal state, seek motives for past behaviour, or theorise about future action (Figure 1). The result is that shifting gaze is a common and expected behaviour for humans, and therefore also one expected to be seen from humanoid characters inhabiting virtual environments.

Unfortunately, animating gaze in an automatic manner remains a difficult prospect. While alternatives exist based on recording the animation of characters’ bodies, for example using motion capture techniques [4], or for capturing eye-movements alone [5], capturing gaze during free-viewing situations remains challenging. Other approaches, where models are constructed from experimental data, are also troublesome: while comprehensive experimental results and models exist for gaze movements taking place in the horizontal meridian [6], far more remains to be uncovered regarding the nature and circumstances surrounding vertical and oblique gaze shifts [7]. Thus, despite the plethora of contemporary characters who must look around, their gaze motions are either animated by hand, or else employ simplified generic models that do not address many challenging, low-level aspects, in particular: (1) the variability in motion between participants when shifting gaze to the same target, (2) the relationship between blinking and gaze shifts, (3) the relative timing, velocity, and contributions of eye-head movements under varying circumstances and (4) viewer perception of the results of models employing these details. This last category is particularly important for behaviour-based animation: the addition of more complicated
models of gaze control may make the system more realistic, but it is of little value if there are no noticeable differences in the final animations from the viewer’s perspective.

This model attempts to address these issues, presenting an eye-head controller (Section III) for the automatic generation of gaze motions for a character based on the concept of head movement propensity; that is, the idiosyncratic tendency for individuals to employ differing head and eye contributions to their gaze motions. Characters are assigned a head movement factor that designates them along a continuum between two categories of extreme head-movers and extreme non-movers. A blink controller (Section IV) links blinking motions to shifts in gaze, referred to as gaze-evoked blinking, to account for modulation of blink rate and the amplitude of eye-lid closure. We also conducted user experiments, with results indicating that these subtle details appear to have a noticeable impact on the perceived quality of the gaze motions (Section V).

II. PREVIOUS WORK

The categorisation described by Poggi et al. [8] is useful for describing some of the types of gaze control models under development. Eyes may be perceived to have at least four different functions: seeing, looking, thinking and communicating. The eyes may be used for capturing information from the environment through visual perception, or orienting the direction of one’s gaze with the goal of obtaining visual information about points of interest. Our eyes may shift when we are thinking or experiencing other endogenous states, and may also be used intentionally to communicate with somebody.

A number of previous works have considered gaze control under a variety of conditions (Section II-A), and in some cases, the generation of accompanying blinks (Section II-B).

A. Gaze Control

Most, if not all systems employing animated characters, employ some form of gaze control system. However, these systems are often proprietary and details are not published. A number of works have focused on gaze control and eye movements at varying levels, usually during conversational settings. Lee et al. use statistical eye movement data to drive saccadic eye movements for a virtual human during conversation [5]. Gaze generation for turning-taking and conversation [9][8], displaying attention and interest during interaction [10], during multiparty situations [11] and for full-body emotional expressivity [12][13] has also been studied.

Gaze control has also been studied at higher levels, relating to visual attention models for detecting salient or task-relevant regions of virtual environments [14]. Peters and O’ Sullivan [15] and Itti et al. [16] orient the head and eyes of an avatar towards locations derived from a neurobiological model of attention. In particular, Itti and colleagues have provided some of the most comprehensive models to date for low-level gaze and blinking [17].

Many challenges are also evident in relation to how gaze may be interpreted. Perceptual studies, in virtual and immersive environments, have considered gaze behaviour, for example, when compared with the graphical appearance of the character [18] and during dyadic interactions [19]. An assessment of eye-gaze [20] also highlights the importance for allowing the correct following of gaze, and its impact on the perception that one may have of the other’s attention towards them [21].

In this work, the primary concern is how the eyes contribute to the role of looking; that is, how the gaze animation takes place, as opposed to the determination of where it should be targeted. In this respect, elements of the work of Lance and Marsella [12] and Itti et al. [17] are of the most direct relevance. Unlike previously proposed models, that presented here provides variation in gaze based on a head movement factor, implements a number of more detailed velocity and timing effects that have been observed in human head movements, and models the role of specialised gaze-evoked blinks during gaze shifts.

B. Blinking

Blinking has been primarily considered when applying eye movements to conversational agents, usually based on internal emotional or conversational state parameters. In the A.C.E. system, for example, an agent’s anxiety level has an effect on the frequency of eye blinking [22]. Blinking is also considered in [17], depending on locations attended to and timing considerations, each blink lasting for a fixed amount of time. Unlike previously published work on blinking, this work considers blinking directly related to gaze shifts, and effects of the gaze shift on blink amplitude i.e. the degree to which the eyelid closes when blinking.

III. EYE AND HEAD MOVEMENTS

When looking around, targets may appear at different eccentricities within our environment; if these eccentricities are outside of the mechanical rotational limits of our eyes, the oculomotor range or OMR (40° - 55° eccentricity in humans), then the recruitment of the head in the final motion is mandatory for aligning the visual axis with the target. Such gaze shifts consist of coordinated eye and head movements in order to bring the foveal region onto the target and may also be common when looking at targets of eccentricities smaller than the OMR.

Gaze, $G$, is the direction of the eyes in space, which consists of the direction of the eyes within the head, $E$, and the direction of the head in space, $H$; see Figure 2 for an illustration of these vectors and Table I for a list of definitions that will be used to describe gaze computations. Thus, Equation 1 describes gaze direction in terms of the eyes and head, where $WS$ is the world-space coordinate frame and $HS$ is the head-space coordinate frame:

$$G_{WS} = H_{WS} + E_{HS} \quad (1)$$

Since the eyes and the head contribute to gaze motions, a primary issue when modelling gaze is the relative contributions of each to the final gaze motion. Although gaze shifts for
Meaning

Final eye vector

Head Movement Factor ranging from 0.0 to 1.0

Current head vector

Target vector from head position to target position

Final head vector

Head Movement Range

Oculomotor Range, -40° and +40° horizontally

Head Movement Range

Head Movement Factor ranging from 0.0 to 1.0

humans and Rhesus monkeys are generally thought to follow a linear relationship linking head contribution and gaze amplitude (see [23]), the contribution of the eyes and head of an individual to the final motion can exhibit a reasonable degree of variability: for example, Afanador and Aitsebaomo [24] found that half of their participants consistently moved their head, even when targets were well within the OMR and head movements were not mandatory. The other half produced head movements only for eccentricities beyond 20° to 30°. Participants were categorised [25] into two distinct groups, head-movers and non-movers.

Fuller [26] further detailed a number of effects that may be used to explain these behaviours. As noted, horizontal human head movements are generally mandatory when the gaze shift demands an ocular orbital eccentricity exceeding the OMR. If a gaze saccade can be executed within this orbital threshold, then the amplitude of the head movement is regarded as a momentum effect that brings the head closer to the target when the head and the target are on opposite sides of the midline.

Previous experiments (see [7] for overview) have indicated a close, general relationship between the contribution of the head to the motion, referred to as gain, given the initial eye position and desired gaze shift. However, as noted previously, the gain may typically vary somewhat from individual to individual. A gaze controller animates the gaze motions of different characters based on head movement propensity and the two aforementioned effects.

A. The Gaze Controller

At the lowest level, the task of the gaze controller is to animate the ‘skeleton’ of the virtual character so that the final configuration is such that the eyes are oriented towards a target location in the environment. The character’s skeleton contains a large number of ‘bones’, many of which could contribute towards the motion itself. The gaze controller presented here is simplified in that it only affects a subset of the character’s bones: the head and eyes of the character. The virtual character’s eye position is represented by a single bone approximating the viewpoint of the character. The orientation of this viewpoint is locked to the orientation of the eyes of the actor. Thus, as the eyes rotate, so too does the viewpoint.

Characters are attributed with a head movement factor, $HMF$, ranging from 0.0 to 1.0, signifying their propensity towards head movement or eye movement; that is, characters vary between being extreme head-movers and extreme non-movers. This attribute is used by the gaze controller to provide simplified midline attraction and resetting effects as described by Fuller. Essentially, this attribute is used to determine the gain, or head contribution, to gaze motions made by the virtual human; if the gain is high, then gaze motions will consist primarily of head movements, while a low gain will result in mainly eye movements.

The gaze controller operates by creating a final head vector $H_f$ and final eye vector $E_f$. Initially, two head vectors are created with respect to the target. The first vector, $HM$, represents the most extreme head movement vector; that is, gain will be maximum when the head is oriented towards the target and the eyes do not make any contribution to the gaze unless the target is eccentric beyond that afforded by head.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M$</td>
<td>Midline Vector</td>
</tr>
<tr>
<td>$HM$</td>
<td>Extreme head-mover vector</td>
</tr>
<tr>
<td>$NM$</td>
<td>Extreme non-mover vector</td>
</tr>
<tr>
<td>$H$</td>
<td>Current head vector</td>
</tr>
<tr>
<td>$H_f$</td>
<td>Final head vector</td>
</tr>
<tr>
<td>$E$</td>
<td>Current eye vector</td>
</tr>
<tr>
<td>$E_f$</td>
<td>Final eye vector</td>
</tr>
<tr>
<td>$T$</td>
<td>Target vector from head position to target position</td>
</tr>
<tr>
<td>$OMR$</td>
<td>Oculomotor Range, -40° and +40° horizontally</td>
</tr>
<tr>
<td>$HMR$</td>
<td>Head Movement Range</td>
</tr>
<tr>
<td>$HMF$</td>
<td>Head Movement Factor ranging from 0.0 to 1.0</td>
</tr>
</tbody>
</table>

TABLE I
DEFINITIONS DESCRIBING GAZE COMPUTATIONS.

1) *Midline attraction* refers to a resistance to head movement away from the midline in non-movers and an increase in the head movement amplitude if a jump in gaze starts eccentrically. When the head is off the midline and gaze is stepped to the opposite side, the head will be moved to the opposite side, unlike when the jump is initiated with the head on the midline.

2) *Resetting* occurs when the eccentricity of a jump is varied, resulting in the stopping position being reset closer to the target. The pooled mean head contribution for the jump from midline to a 40° target was 0.51 (stopping position of 19.6° from the target), while it was 0.73 (stopping position of 10.8° from the target) for a -20° to +20° jump. Fuller notes that this can be thought of as a momentum effect that brings the head closer to the target when the head and the target are on opposite sides of the midline.
movement limits alone. In such cases, the head movement is maximised and eye movement composes the remainder of the orientation (see Figure 3). A second vector, $\vec{NM}$, is constructed to represent extreme non-movers. If the target is within $OMR$, and eye movement is thus discretionary, then extreme non-movers will always use an eye movement to conduct the gaze [24]. If the target is outside of oculomotor range, then $\vec{NM}$ will be aligned such that the eye vector will be at its maximum; that is, the range of $OMR$. Note that any targets that are outside of $HMR + OMR$ can not be looked at by the current algorithm, since eye and head contributions alone are not enough to generate alignment with the target. Such cases could typically be handled by employing an algorithm that accounts for characters’ spine bones in the calculations so that the upper torso may be free to move, but this is currently an issue for future work.

For cases where the current head vector $\vec{H}$ is on the opposite side of $\vec{M}$ with respect to $\vec{T}$, midline resetting is simulated for non-movers by moving $\vec{NM}$ closer to $\vec{H}$ (and thus, closer to $\vec{T}$). The final head vector $\vec{H_f}$ is then calculated as an interpolation of $HMF$ between $\vec{NM}$ and $\vec{H}$ (see Section III-B). The eye vector $\vec{E_f}$ will then be the vector from the eye position to the target (and will always be between 0 and the oculomotor range $OMR$). When the target vector $\vec{T}$ is within $OMR$, non-movers will tend to use mainly their eyes to fixate the target. However, non-movers are more likely to maintain their head position close to the midline due to midline attraction. This means that in certain cases, where the target vector $\vec{T}$ is between the current head vector $\vec{H}$ and the midline $\vec{M}$, this will result in the head being attracted back towards the midline (see Figure 5).

The outputs of this process are two vectors, $\vec{HM}$ and $\vec{NM}$, representing the final eye and head directions for extreme head-movers and extreme non-movers respectively. A high $HMF$ value results in large head contributions to the final gaze animation, while lower $HMF$ involve a greater use of the eyes. Once the final vectors have been computed, the gaze animation must account for temporal details of the motion, as described in the next Section.

B. Dynamics

Given the output vectors, $\vec{HM}$ and $\vec{NM}$, representing the final eye and head directions for extreme head-movers and extreme non-movers respectively, a spherical linear interpolation, or SLERP (see [27]), is used to provide the final eye and head orientations for the specified head movement factor.

It should be noted that the model presented thus far generates only the final head and eye orientations, but does not specify intermediate positioning i.e. the relative timings and velocities of eye and head movements have not yet been accounted for. At this point, a straightforward spherical linear interpolation operation may be conducted for each of the head and eyes, between their initial and final orientations, as was the case in the experiments in Section V.

During actual gaze shifts, eye and head velocities exhibit peaks which are not always related in the same way: peak eye velocities may decline while peak head velocities increase with increasing gaze amplitude and gain (see [6]).

1) Velocity Profiles, Amplitude and Duration: General relations are known to exist in the horizontal meridian between the duration, peak velocity and amplitude. In this model, we generalise the data for vertical and oblique movements. Prototypical relationships are defined for the velocity profiles

---

Fig. 3. Calculation of extreme movement vectors when targets are outside of $OMR$ and outside of $HMR$. (Left) When a target is outside of $OMR$, head movements are mandatory, even for non-head movers. (Right) $HM$ cannot extend beyond the maximum head rotation range $HMR$. Therefore, when the target is outside $HMR$, $HM$ is set to $HMR$ and eye movements are mandatory. In both cases, the extreme non-mover vector $NM$ remains as close as possible to the midline vector $M$.

Fig. 4. The resetting effect. (Left) The target vector $T$ is on the opposite side of the midline $M$ to the current head vector $H_C$. (Right) The extreme non-mover vector $N_M$ remains as close as possible to the midline vector $M$.

Fig. 5. Illustration of midline attraction. (Left) The target vector is between the midline and current head vectors. (Right) The extreme non-mover vector $N_M$ is attracted towards the midline such that the eyes are at the limits of $OMR$.
of the eye and head, according to those described in [7] and
modelled using splines. Splines are altered at run-time for
specific movements based on the maximum (or peak) velocity
for the motion, and the amplitude of the motion i.e. the size
of the head or eye movement, according to whether only the
eyes, or the eyes and the head are being recruited for the gaze
shift.

2) Timing of Head and Eyes: Another factor to account for is the relative timing of the movements of the head and
eyes. In the model presented, this is accomplished by shifting
the profile for the eyes along the temporal axis, so that the
eye movement can happen slightly before, at the same time,
or after the head movement. In all cases, it is ensured that
the eyes reach the target either before or at the same time
as the head. In most cases, where the eyes fall on the target
before the head, it is necessary to simulate the effects of the
vestibulo-ocular reflex as described next.

3) Vestibulo-Ocular Reflex: The vestibulo-ocular reflex, or
VOR, is important for keeping the eyes targeted when the
head is moving. In this model, the VOR must be simulated
to do so for situations when the eyes arrive at the target
first. In practice, it is easily accomplished: once the eyes
have been deemed to land on the target and while the head
continues to rotate, new eye vectors are calculated based on the
difference between the current head direction and the current
target direction relative to the eyes.

IV. BLINKING

Blinking motions, often subtle, may be an overlooked way
of conveying a sense of realism in gaze motions. As with gaze
motions, blinks may be interpreted in many different ways.
Generalities have been described in the literature: individuals
who do not blink or move their eyes may appear to be
preoccupied or engaged, while high rates of blinking may
indicate aroused internal states such as frustration, confusion
or excitement. On average, a person blinks roughly 17,000
times per day, with a “normal” blink rate thought by some
to be in the region of 20 blinks per minute [28]. Each blink
lasts from 20-400 milliseconds, with the primary purpose of
clearing debris from the eye and moistening surface tissue.

The relationship between gaze and blinking is undoubtedly
intricate and easily underestimated. Professional animators and
artists have long recognised this and blinking is treated as an
important factor in creating expressive and life-like characters
[29]. Despite this, little in-depth research into automated
blinking models for autonomous characters appears to have
taken place; most blink models, when published, appear to be
of an ad-hoc nature, accounting solely for blink rate related
to emotional state or conversational role.

A number of factors affect blink rate and can be categorised
as environmental factors and internal factors. Environmental
factors include alterations in temperature, lighting and airflow
that have an effect on blinking, as do factors affecting the
ocular surface, such as wind. Different activities may also
cause changes in blink-rate, for example, engaging in con-
versation or concentrating on a visual task. Blink rate is also
linked to internal psychological and physiological factors; for
example, it may increase with excitement, frustration and
anxiety or decrease with guilt and low mental load. Age,
gender, muscular tension and a variety of factors also appear
to affect blink rate.

A. Gaze-Evoked Blinking

Gaze-evoked blinking motions are those that accompany
saccadic eye and head movements, in contrast to normal blinks
that are elicited by external stimulation such as wind. Many
vertebrates generate gaze-evoked blinks as a component of
saccadic gaze shifts. As noted by Evinger et al. [30], such
blinks would appear to serve the purpose of protecting the eye
during the movement, while also providing lubrication to the
cornea at a time when vision has already been impaired due to
the saccade. Evinger et al. describe three main characteristics
of gaze-evoked blinks:

1) The probability of a blink increases with the size of
the gaze shift. In the study conducted by Evinger et al.,
blinks were found to occur with 97% of saccadic gaze
shifts larger than 33°, while the occurrence of eyelid
activity for 17° eccentricity was only 67%.

2) The initiation of the activation of the eye muscle is de-
pendent on the magnitude of the head or eye movement.
Activation of the eye muscle started after the initiation
of the head movement, but there was a clear tendency
for activity to start before the head movement with large
amplitude gaze shifts.

3) The amplitude of the head movement has been shown to
affect the magnitude of the blink, or how much the eyelid
loses (see Figure 6). In general, the more that the head
moves, the more the eyelid tends to close. For example,
during a head movement of 5° eccentricity, the blink
magnitude will usually be quite small, meaning that the
eye-lids will not close very far. In contrast, eccentricities
of 50° or more will often result in a full closure of the
eye-lid.

B. The Blink Controller

The general characteristics of gaze-evoked blinking detailed
in [30] are implemented in the blink controller. In addition to
normally occurring blinks, the blink controller also takes input
from the gaze controller. When a gaze request is made, relevant
information from the gaze controller, such as the starting time

Fig. 6. Illustration of blinking magnitudes for the virtual human. Magnitudes from left to right are 0% (eyelid fully opened), 50% and 100% (eyelid fully closed).
of the gaze and the gaze amplitude, is passed to the blink controller which then plans and schedules the blink motion for the characters’ eyelids.

The blink motion is planned as follows. First of all, it is determined, based on head movement amplitude, if a blink is to occur. This is conducted probabilistically, where the probability of a gaze-evoked blink occurring is modelled as having a simple linear relationship with respect to the amplitude of the head movement, such that the probability of a blink for targets of 20° eccentricity is 20%, and the probability of a blink for targets of 50° or more eccentricity is 60%. In this way, a gaze evoked blink will always take place for head movement amplitudes of 75° or more.

If a blink event is forecast, then the blink magnitude, specifying by how much the eyelids should close, is calculated. Blink magnitude is modelled as a linear relationship between the amplitude of the head movement, such that the magnitude of a blink for targets of 17° eccentricity is 67% and the magnitude of a blink for targets of 33° eccentricity is 97%.

V. Experiments

The gaze model was simulated on a Dell 2.33 GHz Intel Core 2 Processor, with an Nvidia GeForce Go 7950 GTX graphics card. Experiments were conducted in order to assess the plausibility of gaze and blinking animations created by the system. Six participants (5M:1F) with computer science backgrounds, aged between 20 and 28, were shown multiple animations consisting of varying blink types and head movement factors (see Figure 7 for sample frames). Each animation lasted 30 seconds; participants were asked to complete a questionnaire at the end of each trial, where they rated the realism of the animation on a scale of 1 to 10 and provided a textual description of their impression of the behaviour.

VI. Conditions

Each animation adhered to one of the five following experimental conditions tested, each representing a single or compound method of blinking:

1) Condition NB: No blinking. The character did not blink at all during the animation.
2) Condition RU: Regular unsynchronised. The character blinked according to a set interval of one blink every 3 seconds. Blinks were not synchronised with gaze shifts.
3) Condition GE: Gaze-evoked. The character blinked only when a gaze change took place. The probability of a blink occurring with a gaze change was set to 1.0 i.e. a blink was made every time that gaze shift took place, regardless of how small.
4) Condition PGE: Probabilistic gazed-evoked. The character only blinked when a gaze shift took place, and did so with a probability as given in Section IV-A.
5) Condition R+PGE: Regular and probabilistic gaze-evoked. This was a mixture of the probabilistic gaze-evoked and regular cases. The character blinked at regular intervals by default, and also when a gaze change took place, with a probability according to that given in Section IV-A.

VII. Results

The averaged results obtained over all six participants are depicted in Figure 8. Overall, case NB, where the character did not blink at all, was rated the lowest by all participants. Participants generally agreed that the total lack of blinking was disconcerting.

Case RU (regular interval, unsynchronised blinks) ranked as the third most plausible case. First of all, this seems to indicate that frequent blinking, in the order of one blink every 3 seconds, is an important component for plausible gaze motions. This is also outlined by the results of the case where no blinking took place. More interestingly, however, a number of participants noted a general sense that some of the blinks did not seem natural. This seems to indicate that frequent, periodic blinking is not the only factor leading to the perceived realism of gaze motions. In this case, blinks were not synchronised with head movements, so some blinks occurred at the start of, during, or at the end of a gaze motion or between gaze motions.

Participants ranked case GE (gaze-evoked blinking) as the second most realistic case, mainly due to the fact that they reported the movement to be “synchronised better” and commented that the timing “feels more natural”. Despite this, the deterministic nature of the regular blink pattern, which took place every time a gaze change was invoked, is thought to have detracted from the realism of the animation in a number of cases; as one participant mentioned, the blinks were “too regular, like a metronome”. This can be accounted for by the regularity at which the gaze changes took place. Since the blinking system is linked to a gaze change, if gaze changes take place at regular intervals and the blink probability is 1, then blinks will may appear too dependent on gaze. The results for this case seem to indicate that while synchronisation of blinking with gaze changes is desirable, it should not occur deterministically every time the character makes a gaze-shift.

Case PGE (probabilistic gaze-evoked blinking) was judged to be of low realism, with an overall score of 4.9, which seemed a surprising result. However, it can be explained by the fact that, according to the formula in Section IV-A, for most low eccentricity gaze changes, there is a low probability that a blink will occur. Therefore, when probabilistic gaze-evoked blinking was the sole model used, the length of each animation (30 seconds) and number of gaze shifts during this time may not have generated enough blinks and led to a similar situation as the NB case, where no blinking took place.

Indeed, in this instance, it seems that it was not the synchrony of the blinks that participants found unnatural, but the fact that few of them occurred. The results of this case indicate that probabilistic gaze-evoked blinking, as modelled in Section IV-A and used in isolation, does not provide plausible gaze motions when gaze changes of high eccentricity were not commonplace, due to the lack of frequency of blinking.
The final case, R+PGE, mixed probabilistic gaze-evoked blinking with regular blinking. It was rated as the most plausible of the animations by the participants, with a score of 7.7. When considered with the results of the other cases, it seems to support three working hypotheses:

1) The synchrony of blinking with gaze movements (i.e. gaze-evoked blinking) is an important factor for the plausibility of gaze animations.

2) Gaze-evoked blinking should be probabilistic in nature/not be totally deterministic, so as to avoid the impression of programmed or robotic motions.

3) Probabilistic gaze-evoked blinking alone is not enough to ensure plausibility; normal, frequent blinks are a necessary component of plausible gaze motions.

Some of the limitations previously mentioned regarding the gaze generation system were also evident in the results of the experiments: a number of participants noted their awareness of irregularities in the timing of eye and head motions (see Section III-B), since a simplified version of the model was used in an attempt to minimise the number of cases to be tested in the experiment.

VIII. CONCLUSIONS AND FUTURE WORK

We have presented a psychologically inspired model of gaze and blink coordination for the animation of gaze motions for virtual characters. Eye and head contributions to the final motions are based on head movement propensity in order to provide diversity in the animations; blinking is gaze-evoked, with eyelid closure probability and magnitude dependent on head movement amplitude. This paper therefore contributes two important enhancements for gaze models: variations in head contributions to provide gaze diversity and blink synchrony with head motion for improved plausibility of gaze shifts.

The experiments were limited in both population and scope, raising many more important questions for future consideration. First of all, a larger participant population is desirable for future experiments, with a better ratio between males and females. This is particularly important, as gender, in terms of both the participants and the characters, is one of the many factors known to influence gaze perception. Secondly, the experimental corpus consisted of animations using constant head and eye velocities, where the eye and head movements began and finished at the same time. Participant perception when these factors are altered would be of great interest. Another important issue is the context of the interaction: in these experiments, participants were not provided with any context for the character’s gaze motions. It is likely that perception of gaze will not remain constant over these factors and could be interpreted differently, for example, during conversational and shared attention situations, based on role (as speaker or listener) and when the character engages in mutual gaze with the viewer.

Finally, it must be noted that the model presented here is
intended as a low-level gaze component: it deals solely with gaze shift commands. It does not consider higher-level aspects, such as gaze allocation according to conversational, emotional, or attentional factors, but rather could be controlled by such models. For example, a visual attention model could determine gaze targets within the environment and their priority, and pass them to the gaze model (as conducted in [17]), and a saccadic eye-movement system, such as that proposed in [5] could also complement the model when gaze shifts recruiting the head are not occurring. A difficult issue is how multiple constraints can be balanced; after all, the eyes can only be in one place at one time. During a conversational situation, where the duration of gaze at the other interactor is vital for signalling engagement and one’s will to maintain the interaction, it remains an intriguing question as to how stimuli in the periphery may also be attended to, and gaze modulated according to emotional state. Ultimately, these factors must all be married in some manner if more believable behaviours are to be produced. It seems likely that the delicate balancing act conducted by humans under these situations can only be elucidated by further experimentation, not only in relation to gaze motions, but also the visual attention mechanisms underlying them.

ACKNOWLEDGMENT

The author would like to thank the reviewers for their helpful and informative comments.

REFERENCES


