Gaze Behavior, Believability, Likability and the iCat *

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Abstract

The iCat is a user-interface robot with the ability to express a range of emotions through its facial features. This paper summarizes our research whether we can increase the believability and likability of the iCat for its human partners through the application of gaze behaviour. Gaze behaviour serves several functions during social interaction such as mediating conversation flow, communicating emotional information and avoiding distraction by restricting visual input. There are several types of eye and head movements that are necessary for realizing these functions. We designed and evaluated a gaze behaviour system for the iCat robot that implements realistic models of the major types of eye and head movements found in living beings: vergence, vestibulo ocular reflexive, smooth pursuit movements and gaze shifts. We discuss how these models are integrated into the software environment of the iCat and can be used to create complex interaction scenarios. We report about some preliminary user tests and draw conclusions for future evaluation scenarios.

Keywords: believability, user-interface robot, iCat, social gaze behaviour.

1 INTRODUCTION

The iCat is a robotic research platform that has been introduced by Philips to investigate human-robot interaction with the aim to apply the results of this research in smart home environments, see Figure 1. Its face has 11 actuators, one for each eyebrow and eyelid, one for the vertical eye movement, two for horizontal eye movement and four to control each corner of the mouth. These actuators enable it to show a wide variety of expressions, see Figure 1.

Figure 1: Left: The iCat has various sensors including touch, vision and sound sensors to perceive our physical world with. Right: The iCat is able to show various facial expressions. From left to right: happy, angry and surprise.

The neck and body movement are controlled by two DC motors. Input devices include a camera in its nose, a proximity sensor in the left paw and two microphones to record stereo sound. It also has multicolour LEDs in its ears and paws and a speaker as output devices. The reason iCat lacks mobility is so that the focus of research done with it can be restricted to aspects of human-robot interaction, such as believability.

The iCat is mainly controlled by "playing" animations, predefined sequences of actuator values. This precise control over motor positions results in more lifelike behavioural animations then traditional feedback control loops that are normally used in robots (van Breemen, 2004). The animation tools and programming environment for the iCat are provided by the Open Platform for Personal Robots (OPPR).

In this paper we focus on the role of gaze behavior for increasing the believability and likability of the iCat (and similar robotic devices). Gaze behaviours differ with respect to when, where and how somebody looks at something. *When* to look is investigated in studies where the function of gaze during social interactions is looked at. See for instance the research done in the AMI project[1]. When do we look at a speaker, when do we look away and what information do we convey by doing this. *Where* to look is based in the area of cognitive psychology and covers aspects such as which cues from the environment attract our visual attention. *How* to look has its roots in the biological and neurophysiological field where the movements of the eye and combined head movements are studied.

As mentioned above, the main objective of this work is to increase the believability and likability of the iCat through enhancing the naturalness of the gaze behaviour. In this study we have focussed on improving the way the iCat looks (that is the *how* question; and to a minor extent the *where* question) and measure what effect this more natural behaviour has on the perception of the iCat by users.

In order to measure believability and likability, we should have clear definitions of these concepts. Both criteria that are used to evaluate the gaze behaviour system are abstract concepts that cannot be measured absolutely. The evaluation will therefore be done with a user test focusing on a person's perception of an iCat with gaze behaviour to one without it.

A useful definition of believability is given by Dautenhahn (1998): because humans seem to be naturally biased toward identifying self-propelled movement and intentional behavior, believability is not necessarily dependent on complex or realistic behaviour, but more influenced by a user's subjective perception of a characters behaviour (i.e., can a person match the characters behaviour to what they have observed in living beings). Believability can not be accomplished by focusing on a single behavioral aspect, but should rather be seen as a combination of various attributes (including but not limited to intelligence, reactivity, emotion, etc.) blended together. An overview of requirements that contribute to the believability of a character is given in Loyall (1997).

Likability is a more straightforward concept. When using and/or interacting with a system the capabilities of the system and the feedback it provides influence a user experience. We hypothesize that the gaze behaviour system, which adds an element of natural communication to the iCat, will elicit positive emotions in a user during the interaction. The reported level of positive emotions is called a users level of likability of the iCat. We use the following definition of likability. A character is likable if, from the perspective of a person interacting with it, the character elicits positive emotional experiences within them.

From studies such as Nass and Moon (2000) we see that people have an innate inclination to react in a social and natural manner to those things we perceive as being able to have personality. This means we can build technology that allows us to communicate naturally with them. By natural communication we do not only mean speech, but all aspects of the way humans exchange information while interacting with each other. This also includes facial expressions, body posture, gestures, gaze direction and tone of voice. Because there should be a certain degree of consistency been between a robots embodiment and its behaviour, the fact that the iCat has eyes causes people to think that it can see. We contribute to the iCat's communicative capabilities and attempt to convince people that the iCat can see by equipping it with a gaze behaviour system.

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

In Section 2 we summarize some of the functions and effects of gaze. The design of the gaze behaviour system is discussed in Section 3. The evaluation of the gaze system can be found in Section 4. We conclude with the conclusions and future work in Section 5.

2 FUNCTIONS AND EFFECTS OF GAZE

In this section we summarize some of the functions and effects of gaze with regard to personality, emotions, reactivity & responsive and self motivation.

The major function of gaze is clearly to exchange information through the visual channel. The direction of gaze is mainly determined by the choice of what one wants to attend to. Gaze may be also be turned away from attention-seeking objects to avoid distraction for instance when one has to concentrate on thinking. However, gaze has many side-effects and functions build on this basic determinant.

A study of eye contact during two person social interaction is given by Argyle and Dean (1965). This study states that eye contact may serve a number of functions. Firstly it has an feed-back seeking function. A speaker will often look away during talking to avoid distraction and seek eye contact on completion of the speech to observe the reactions of listeners. Secondly it can signal that the interaction can proceed. Other examples of information communicated through gaze are given in Argyle and Cook (1976). One of the more notable examples is that there is a relation between the liking of another person and the amount of gaze. Feelings of embarrassment, guilt and sorrow often result in aversion of gaze.

Several experiments have been done to evaluate the perception of eye gaze. They show that the information perceived through gaze is largely similar to that which was conveyed. An interesting exception is that large amounts of gaze are perceived as dominant whereas dominant people gaze less at people they interact with. An experiment by Argyle et al. (1974) investigates the influence of the amount of gaze (from no gaze to continuous gaze) during a conversation. The results show that higher amounts of gaze lead to a higher score on a dominant-submissive scale. Also more gaze increases the score on a agreeable-disagreeable scale up to a certain point after which it is evaluated less agreeable.

Given the many effects of gaze behaviours on conversational flow, emotions and interpersonal variables it plays an important role in the appreciation of a person or an agents in terms of believability and likability.

2.1 EFFECTS OF GAZE ON BELIEVABILITY AND LIKABILITY

Believability and likability of a (robotic) character can not be accomplished by focusing on a single behavioral aspect, but requires a well balanced blend of various attributes (Loyall, 1997). The aspect to which gaze behaviour contributes to are: personality, emotion, reactivity and self motivation.

2.1.1 PERSONALITY

The single most important aspect of believability is personality. All the details of a character's behaviour and emotional responses to situations, the (unusual) traits a character has, are what define the individual and it is especially that which makes the individual interesting. Somebody's gaze behaviour in a social context says a lot about his/her personality. Argyle (1967) says that the eyes may provide clues to aspects of personality that determine a persons behaviour in similar situations. Libby and Yaklevich (1973); Larsen and Shackelford (1996) provide an overview of personality determinants that are related to different types of gaze behaviour. They find that gaze is mainly associated with personality traits such as shyness, dominance, need to give or avoid affection and self-esteem.

2.1.2 EMOTION

From the traditional character-based arts and the field of animation it is clear that emotion also plays an important role in believability. Therefore a character should appear to have appropriate

emotional reactions and be able to show them in some way and at appropriate times. Research into the role of gaze in social contexts has shown that it is of the most significant forms of non-verbal communication and previous research into gaze shows that clues about various emotions are communicated to an interaction partner through one's gaze (Argyle and Cook, 1976; Kimble and Olszewski, 1980; Libby and Yaklevich, 1973; Emery, 2000). Primary methods for conveying emotion (mainly sexual attraction, love, shame and sorrow) through gaze is the amount of time spent looking at an interaction partner and the direction to which the eyes are averted.

To be believable a character needs to communicate the same (emotional) message with all its body parts. The face, body, eyes, voice, etc., must work together to express the same message. If a character has eyes then they should also be used in the expressiveness of the character. Consider this: how convincing is a characters happiness, when re-encountering an old friend, to an observer if the character does not even look at this friend? This notion is confirmed in a study by Adams et al. (2003) which shows that the direction of somebody's gaze actually influences how strong our brain reacts to the emotions they display. That this is consistent with what is conveyed by people is concluded from an experiment by Kimble and Olszewski (1980). They show that more direct gaze is maintained when emotionally heavy messages are conveyed.

2.1.3 Reactive and Responsive

A believable character should appear to react to changes and stimuli from it's environment and its responses should also occur at a reasonable speed. If the response lags the stimuli too much, the reactiveness of the character will likely have a negative influence on the believability. Humans and animals often exhibit involuntary gaze shifts as a reaction to (unexpected) environmental stimuli (Carpenter, 1988). This type of behaviour should also be exhibited by a believable character. To show that it has become aware of something that has happened in the environment it should direct its visual attention in the direction of the stimulus.

2.1.4 Self Motivation

Apart from reacting to stimuli from it's environment, a character should do things on it's own accord because this reflects its internal drives and desires. A person's belief in a character will quickly diminish if the character sits still when the environment ceases to provide suitable stimuli. If a character in this situation were to inspect its surroundings or casually gaze out the window, this would likely lead to increased level of belief because this gazing then reveals some degree of self motivation in a character. This idea has been the subject of a variety of research projects. Salvucci (1999) looked at mapping eye movements to cognitive process based on the idea that eye movements provide a window into a person's thoughts and intentions. He proposes a set of algorithms that are able to interpret eye-movements as accurately as human experts. Libby and Yaklevich (1973) say that when a person is engaged in deep thought they will often look in upward direction to avoid visual distraction and Williams (2001) mentions that saccadic eye movements can show shifts in a character's chain of thought.

3 Design of a Gaze Behavior System for the iCat

In this section we focus in the design of the gaze behaviour system of the iCat. Special attention is paid to vestibulo ocular reflex, gaze shifts, vergence and smooth pursuit.

3.1 Gaze movements

Eye and head movement is important to humans because the density of photo receptors on the retina is highest in the fovea, a spot located nearly directly on the optical axis. A persons gaze must be such that the region of interest falls on the fovea (Purves et al., 2001). This enables our high visual acuity when focusing on a certain point and is called *foveated vision*. There are four major type of eye and head movement that are important for gaze behaviour and must be simulated by the gaze behaviour system:

- **Gaze shifts** are movements that change the focus of gaze from one point to another. They can be extremely small or very large, requiring the coordination of the head. Small gaze shifts without head coordination are called saccades. They can be induced voluntarily but often occur reflexively.

- **Vergence** movements are when the eyes move in opposite direction in the horizontal plane in order to bring an image near the fovea of both eyes. They are mainly voluntary and relatively slow.

- The **vestibulo ocular reflex** generates eye movements that compensate for head movement. It utilizes information from the balance system to move the eyes in opposite direction of the head.

- **Smooth pursuit** is the visual tracking of a moving object. This system uses visual feedback and prediction to generate coordinated eye and head movements stabilizing the image of the object on the retina.

3.2   REQUIREMENTS

The gaze behaviour system must fulfill the following three requirements. Each is elaborated on and worked out in the remaining sections.

First A point in space where the iCat's gaze should be directed is an input for the gaze system because the function of gaze (the visual as well as the social function) are realized by altering or maintaining the point where gaze is directed.

Second In order to alter or maintain the gaze target the system must implement models of the four major types of eye and head movement: vergence, vestibulo ocular reflex, smooth pursuit movements and gaze shifts.

Third The system needs to fit into and interact with the current software environment and control the iCat hardware so that it can be used to create complex interaction scenarios.

3.3   INTEGRATION INTO EXISTING ENVIRONMENT

The gaze behaviour system will drive certain iCat actuators that correspond with the body parts involved with gaze movements. Because of this it needs to interact with the existing iCat control software, the animation engine, which also drives the iCat hardware. Animations are rendered onto the iCat hardware by the animation engine at fixed speed of 10 frames per second (fps). The engine has a number of channels in which animations can be "played" and is able to merge animations together or to fade one animation into the next. Apart from predefined animations, the engine also has the ability to render so called behaviours which are "dynamic" animations written in the interpreted programming language Lua.

A number of different body parts are involved with gaze movements, namely: the eyes, head, upper and lower eyelids, pupil size and pupil color. The iCat has actuators for the following body parts:

Eyes: Controlled by the $left\_eye$, $right\_eye$ and $eyes\_vertical$ actuators.

Head: Controlled by the $body$ and $neck$ actuators.

Upper eyelids: Controlled by the $left\_eye\_lid$ and $right\_eye\_lid$ actuators.

The output of the animation engine can be seen as the current state of the embodiment and is an input for the gaze behaviour system. This is a vector of actuator positions as shown in equation 1 (note that only the actuators that are relevant for the gaze behaviour system are specified). The output of the system is a modified (only actuator values relevant for gaze movements are altered) vector. How the system should integrate into the existing environment is depicted in Figure 2.

$$\vec{x} = [x_{body}\, x_{neck}, x_{left\_eye}, x_{right\_eye}\, x_{eyes\_vertical}, x_{left\_eye\_lid}, x_{right\_eye\_lid}, \ldots]^{t} \qquad (1)$$
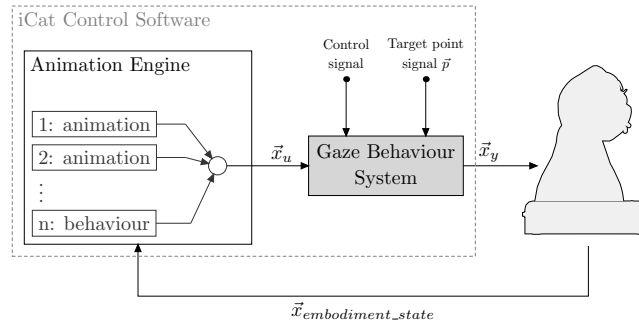
Figure 2: The figure shows how the gaze behaviour system integrates with the existing soft- and hardware environment.

3.3.1 THE GAZE TARGET POINT

The gaze behaviour system requires an input signal that specifies where the iCat's gaze should be directed. This signal is shown in Figure 2 as $\vec{p}$. To simulate the iCat gazing at a specific points in 3-dimensional space we use a standard right-handed Cartesian coordinate system.

Often different situations require a different reference point for a set of coordinates. When estimating positions using the stereo microphones one may want to use a different reference point than somebody doing the same using visual information from the camera. To accommodate this we need a number of coordinate spaces.

World reference coordinates This is a fixed coordinate space that enables us to refer to the world with the iCat as a reference point. The origin of this space is located in the center of the base of he iCat.

Camera coordinate space This coordinate system makes it possible to ascertain in which direction the camera is looking and where, form the viewpoint of iCat, an object is located. The origin of this space is located at the lens of the camera.

Head gaze coordinate space This coordinate systems is needed in order to determine the head gaze direction. The origin of this space is located directly between the center of the eyes.

Eye gaze coordinate space Correspondingly we have the same needs for eye gaze direction. This coordinate system has the same origin as the head space, but is influenced by the vertical and horizontal rotations of the eyes (i.e. if the eyes rotate, this coordinate space rotates with then).

3.3.2 GAZE MOVEMENT MODELS

The gaze behaviour system implements models of the four major types of eye and head movement, vergence, vestibulo ocular reflex, smooth pursuit movements and gaze shifts as sub systems. Vestibulo ocular reflex, smooth pursuit and gaze shift movements alter or maintain the direction of gaze where as vergence movements focus both eyes on the same point somewhere along the line of gaze. Therefore the vergence sub system is always active and only one of the other three sub systems is active at a certain time. The gaze behaviour system has a control signal (see Figure 2) to switch between these three sub systems. More detailed information on the gaze system can be found in Meulemans (2007).

Vestibulo Ocular Reflex

Recall that the vestibulo ocular reflex (VOR) generates eye movements that compensate for head movement. It utilizes information from the balance system to move the eyes in opposite direction of the head. The effected embodiment parameters are the horizontal position of the left and right eye and the vertical position of both eyes simultaneously. The algorithmic procedure is as follows; the coordinates of target point are first transformed into head gaze coordinates called $\overrightarrow{p}$. Afterwards the following angles are computed:

$$\overrightarrow{x}_{left\_eye} = \overrightarrow{x}_{right\_eye} = \arctan(\overrightarrow{p}_x / \overrightarrow{p}_y)$$

$$\overrightarrow{x}_{eyes\_vertical} = \arctan(\overrightarrow{p}_z / \overrightarrow{p}_y)$$

If these eye angles lie outside the achievable scope, due to hardware limitations of the iCat, the nearest achievable eye angles are chosen. From a study of Collewijn and Smeets (2000) it follows that latency for VOR is around 10 ms. Hence we do not model this latency.

Smooth pursuit

Recall that smooth pursuit is the visual tracking of a moving object. This system uses visual feedback and prediction to generate coordinated eye and head movements stabilizing the image of the object on the retina. First the target point is transformed to body coordinates and afterwards
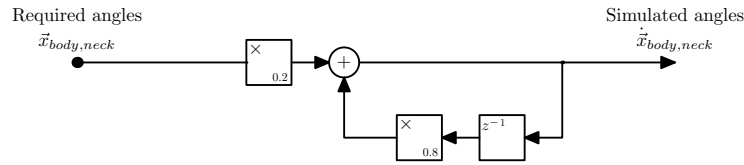

Figure 3: The control diagram for the smooth pursuit

the a dynamical model, Figure 3, is used for tracking.

Gaze shifts and saccades

Gaze shifts and saccades change the direction of visual attention from one point to another. For humans they range from very small to very large amplitudes and can take between 20 and 300 milliseconds to complete. Also for large gaze shifts where the coordination of the head is required, there are variations in the amount of head contribution and in the latencies before the head and eyes start moving. These dynamic properties are influenced mainly by if the gaze shift is a reflexive response or a voluntary shift of visual attention. Our model incorporates the dynamics of a real gaze shift system as much as possible. The system is designed after a system proposed in Freedman (2001) which has been adapted for the iCat. The gaze shift model is spilt into a number of elements, namely a system that determines head contribution and head and eye movement simulators. The input is the target point in world coordinates. The coordinates of this target point $\overrightarrow{p}$ is transformed into head gaze coordinates (this determines where the target point is w.r.t. the direction of the head) and eye gaze coordinates (this determines where the target point is w.r.t. the direction of the eyes). From this one can easily calculate the horizontal and vertical gaze displacement angles and the initial eye positions. Using these the contribution of the eyes and the head to the gaze shift can be calculated. For gaze shifts smaller then a threshold there is no head contribution to the gaze shift, only eye gaze shift.

The movement dynamics of the for the head and eyes are depicted in Figure 4 and Figure 5.
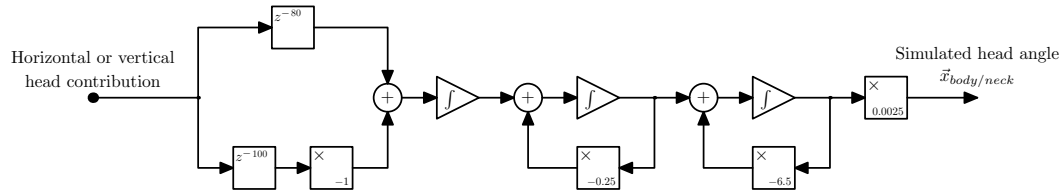

Figure 4: The control diagram for the head movement for a gaze shift of the head.

The head simulator is based on the models found in Freedman (2001). An example of a horizontal gaze shift can be found in Figure 6.
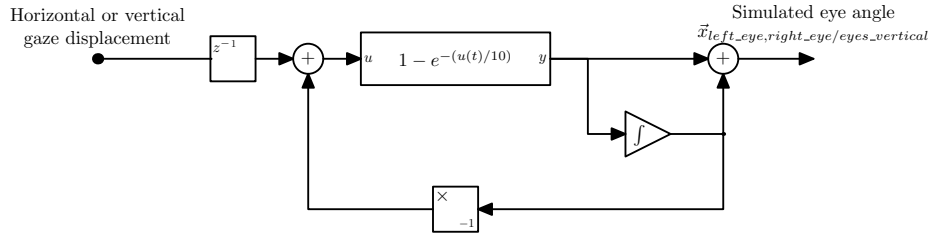
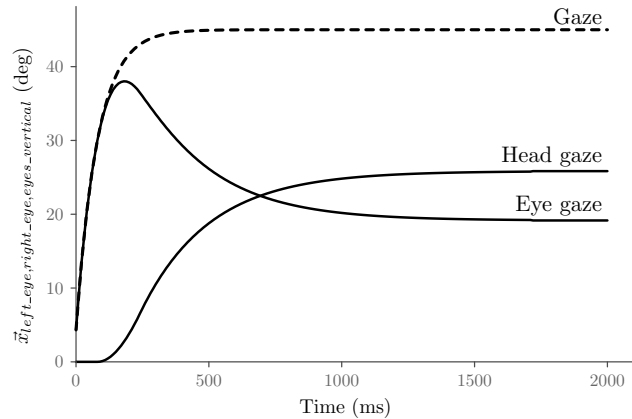Figure 5: The control diagram for the eye movement for a gaze shift of the eyes.

Figure 6: An example of an horizontal gaze shift.

Vergence control

The other gaze models will calculate the horizontal angle of the eyes as if their origins were equal to the origin of their parent joint (Eyes vertical), i.e. discarding their offsets. This means that the eyes will be looking in a certain direction, but focused at infinity. The vergence control system modifies the horizontal eye angles to converge on the target point distance.

Independent which of the above subsystems is active the gaze behaviour system goes through the same processing steps:

Step 1: Transform 3D target point to required embodiment angles. The 3-dimensional target gaze point and the current state of the embodiment are used to calculate the embodiment angles required to gaze in the direction of the target. The current state of the embodiment, represented as in equation 1, is another input for the gaze behaviour system. It is provided by the animation engine. The animation engine outputs actuator positions as values for the embodiment state vector which are transformed into joint angles by the gaze behaviour system.

Step 2: Simulate gaze movement dynamics. The gaze shift and smooth pursuit subsystems simulate the movement from the current embodiment state to the required embodiment state over a period of time. This requires the current and required states of the embodiment and the target point signal. The vestibulo ocular reflex model is a direct response to the current embodiment state therefore does not simulate movement dynamics.

Step 3: Alter angles to converge on target distance At this stage the horizontal eye angles are point in the correct direction, but their focus is on infinity. The vergence sub system alters the angles (which are initially equal) to converge on the target point distance. This requires the 3D target point.

Step 4: Adjust eyelids for vertical gaze direction and blinks This step alters the position

on the eyelids so that the pupils are not covered by them when the gaze is pointed in upward direction. This system also implements blinking.

4   Evaluation of the Believability and Likability

In this section we focus on the methodology behind the user test and evaluate the results in order to asses the believability and likability of the gaze behaviour system. Because both believability and likability abstract concepts and can therefore not be measured on an absolute scale, we need to compare the perceived believability and likability of a character *with* gaze behaviour to one *without* gaze behaviour. More precisely we try to answer the following question:

> *What is the effect of the iCat gaze behaviour on a person's belief in the life of the iCat and their liking of the iCat?*

The hypothesis is that the gaze behaviour system for the iCat will have an significant influence on these factors, i.e. the iCat will be perceived to be more believable and/or likable. Further more we also expect that people deem the iCat more likeable when it exhibits more natural gaze behaviour.

4.1   Methodology

To test the hypothesis an experiment was conducted in which participants engage in two interaction sessions with the iCat. During one condition the gaze behaviour system was used and in the other condition static animations were used.

4.1.1   Participants

A total of 18 participants (8 males and 10 females) for the experiment were recruited internally at the High Tech Campus facilities where Philips Research is located. The criteria used during the selection process were that participants had no prior interaction experience with the iCat and that they were sufficiently adept in the English language. All participants signed a consent form at the beginning of the experiment and during the experiment they were offered chocolates as gratitude for their participation.

4.1.2   Design

The experiment was a within-subject design with two conditions, with (test condition) and without (control condition) the implemented gaze behaviour system. Participants interacted with both versions of the iCat and this was done in a balanced order, i.e. half of the participants first interacted with the iCat in the experimental condition followed by the control condition and half of the participants started with the control condition followed by the experimental condition.

4.1.3   Setting

The experiment took place in the Philips Homelab. During the experiment, participants were seated at the dining table in the living room behind a laptop computer. The iCat was situated on the table, within the users peripheral field of view. During the experiment, the experimenter was seated in the control room, from which it is possible to monitor all activity in the lab through the many cameras and microphones. The experiment setting is shown in Figure 7.

The evaluation of the believability and likability focused on a person's perception of the character which was measured with a paper-and-pencil questionnaire and a semi-structured interview. Both the questionnaire and interview were in English.

As there seems to be no literature concerning the (subjective) measurement of believability, a new questionnaire has been designed that focuses on those aspects of believability that are generally influenced by gaze: personality, emotion, reactiveness and self motivation (Section 2.1). For each of these aspects we have formulated four to eight items per aspect, in the form of statements. The

Figure 7: In the setting of the experiment the participants were located at the dinning table in the living room of the Homelab with the iCat to their left.

participants were asked to rate agreement with each item on a five point Likert scale (1: Strongly disagree, 2: Disagree, 3: Neither agree nor disagree, 4: Agree, 5: Strongly agree). Table 1 gives an overview of all the items and the factor they belong to.

During the interview the participants were asked more direct questions about how they perceived the lifelikeness and their likability of the iCat. Participants were also asked what they thought of the task they were asked to perform during the experiment in order to filter out possibly biased responses.

4.1.4 Procedure

During each session the participants were asked to answer five to ten multiple choice general knowledge questions that appeared on the screen of the laptop in front of them. They were allowed to use the computer to look up the answers to the questions. The questions have been chosen so that on average 60 to 70 percent of the answers will need looking up. Answers were then checked with the iCat who indicated if they were correct or incorrect so that the users attention was forcibly drawn toward the iCat a number of times during the experiment. Independent of the correctness of the answer, the user continued with the next question. A script of the experiment scenario is given in Table 2.

The experiment has a so called 'Wizard of Oz' setup where the iCat the users interact with is partly controlled by the experimenter.

4.1.5 The evaluation protocol

For the control condition the iCat gaze movement is animated using static animations. In the test condition, the models implemented by the gaze behaviour system will replace most animations of the control condition. The animations displaying happiness and sorrow will be kept the same and are rendered over the gaze behaviour using the merging capabilities of the animation engine. The activation of the animations/behaviour as a response to the environment will be controlled by the experimenter. For example, in step 2 of the scenario, when the participant seeks the attention of the iCat the experimenter will start the animation or signal the behaviour that focuses the attention of the iCat on the participant.

We set up the experiment so that the different modes of gaze fit adequately in the interaction. The following sections describe how and when the models are applied and what difference in the participants perception we attempt to invoke.

Vestibulo Ocular Reflex

When a participant informs the iCat of his or her answer to the question, the iCat responds by nodding or shaking its head. During this movement in the test condition the eyes will remain fixed on the participant, such as is normal when humans perform this type of gesture. For the

nr.	Item	nr.	Item
Personality			
1	The iCat was confident	4	The iCat was shy
2	The iCat seemed deceptive	5	The iCat acted submissive
3	The iCat acted dominant	6	The iCat seemed honest
Emotion			
7	The iCat showed emotion in it's reactions	11	The iCat displayed sadness
8	The iCat recognized my feelings	12	The iCat displayed happiness
9	The iCat was empathetic	13	The iCat seemed to dislike me
10	The iCat cared for me	14	The iCat seemed to like me
Reactiveness			
15	The iCat was responsive to the environment	17	The iCat acted conscious
16	The iCat recognized my presence	18	The iCat seemed to be aware of it's surroundings
Self Motivation			
19	The iCat appeared to think	21	The iCat was interested in it's surroundings
20	The iCat was interested in me	22	The iCat gave me attention
Likability			
23	I think the iCat was kind	28	I Dislike the iCat
24	I think the iCat was unkind	29	The iCat's behaviour was nice
25	The iCat was friendly	30	The iCat's behaviour was awful
26	The iCat was unfriendly	31	The experience was pleasant
27	I Like the iCat	32	The experience was unpleasant

Table 1: Each aspect of believability has a group of items associated with it. This table gives an overview of all items and denotes the factor to which they belong. A users rates his or her agreement with an item on a five point Likert scale.

1.	The participant sits down in front of the desk. The iCat, which is initially sleeping, wakes up, looks at the user.	30 sec.
2.	A question appears on the screen and the iCat indicates this by looking at the screen. The participant proceeds with either searching for the answer on the computer or tries to recall the answer from his or her memory.	0-3 min.
3.	The participant seeks the attention of the iCat by gazing in its direction and presents his or her answer. The iCat thinks about the answer and then indicates the correctness of the answer by nodding or shaking its head accompanied by an appropriate emotion.	30 sec.
4.	During the experiment the iCat will react once to an event that occurs in the environment (generally this will be as passing truck or car which happens frequently) that can been seen and heard through the windows of Homelab that the user is facing with his or her back. *(Depending on the amount of time elapsed (no more than 9 minutes) go back to step 2 or continue with step 5)*	≤ 9 min.
5.	The screen indicates that the session is completed which is also indicated by the iCat. The iCat then falls asleep again.	30 sec.

Table 2: For both the test and the control conditions the following scenario was used. The behaviour of the iCat will be partly controlled by the experimenter according to a predescribed protocol. The total duration of the experiment should be approximately ten minutes.

control condition the eyes will not counter rotate in relation to the head movement, but remain still. Because the iCat expresses some emotion during this movement we expect this emotion to be perceived more strongly when the eyes remain focused on the participant.

SMOOTH PURSUIT

The smooth pursuit will be used to keep focus on the participants face during various parts of the experiment. For example when the iCat and the participant are attending to each other, in the test condition the iCat's eyes stay focused on the participant when the participant moves. We expect this to have an effect on self motivation (iCat has some interest in the participant) and on reactivity and responsiveness (iCat is aware of the participant). During the control condition the iCat's gaze will not follow the user (or move its eyes and head at all), but stay in the pre-animated position.

GAZE SHIFTS

From time to time the iCat's gaze will shift between different points of visual attention in the room. The iCat will often shift its gaze from the participant to the screen of the laptop and visa versa. For example, after indicating if a question was right or wrong the iCat will look from the participant to the screen to indicate the next question. Because the user is likely looking at iCat at this time the user should have a good view of this behaviour (which is naturally also the case for the previous two models). When the user is busy using the laptop the iCat will loose interest in the screen and the participant and look around the room. Also, once during the experiment, the iCat will respond with a gaze shift to something that happens outside. When the iCat's focus is on a particular object, it will simulate "scanning" the object by making small gaze shifts quickly after each other (on average every second). During the control condition, the iCat will display the same type of behaviours (except "scanning"), but using static animations which do not include movement dynamics. We expect gaze shifts to have and effect on the perceived reactive and Responsiveness and on the degree of self motivation of the iCat.

BLINKING

In both conditions the iCat will blink its eyes. In the control condition this is every three and a half seconds and in the test condition the period between blinks and the duration of one blink vary. Also, in the test condition, gaze shifts will often be preceded by a blink. We expect blinking to have an overall effect on believability because it introduces movement at regular (and not fixed as in the control condition) intervals.

GENERAL GAZE BEHAVIOUR

Personality is to some degree affected by all types of gaze movements, but mainly be smooth pursuit and VOR because the amount of gaze the iCat focusses on the user is determinant for this. Likability is also effected by the gaze behaviour system as a whole because it introduces "something extra" to the iCat's capabilities.

4.2 RESULTS

In this section we will elaborate on the found outcomes of the experiment.

4.2.1 QUANTITATIVE DATA

First we calculated the Cronbach's Alpha for each factor of the questionnaire. (The Cronbach's Alpha is a measurement for testing the reliability of items that belong to the same scale.) The results are shown in Table 3. Correlation between items in the personality scale was very low. This likely has to do with the factor that the questions are directed toward certain personality traits and not to personality in general. Because of this we did not evaluate items of personality as a group. Items 7,9, and 13 did not have a corrected item-total correlation higher then 0.20 and

it was decided to remove it from their scales. The Cronbach's Alpha for emotion is on the low side, but we consider it acceptable for the type test performed.

Scale	Items included in the factor	Alpha
Emotion	8,10,11,12,14	0.655
Reactiveness	15,16,17,18	0.767
Self Motivation	19,20,21,22	0.694
Likability	23,24,25,26,27,28,29,30,31,32	0.915

Table 3: Cronbach's Alpha for emotion, reactiveness, self motivation and likability factors.

To find out whether there is a significant variance in the way participants perceived the differences between the gaze behaviour of the two iCats, a Wilcoxon signed rank test was conducted for all items of the questionnaire. This is a non-parametric test to compare related samples. The results of this test per item for significant ($p < 0.05$) and approaching significant ($p \approx 0.05$) p values are given in Table 4.

Item	Scale	Z-score	p-value	Direction
The iCat was confident	Personality	-2.460	0.014	Control > Test
The iCat was friendly	Likability	-1.933	0.053	Test > Control
The iCat seemed honest	Personality	-2.121	0.043	Test > Control
The iCat gave me attention	Reactiveness	-1.930	0.054	Control > Test

Table 4: Items that are statistically significant with their z-score, p-value and the direction of the difference

The Wilcoxon signed rank test was conducted for the factors emotion, reactiveness, self motivation and likability. The results show far from significant results cf. Table 5. There is however in all cases a slight tendency toward the test condition scoring higher than the control condition.

Item	Z-score	p-value	Direction and means
Emotion	-0.630	0.528	Test > Control
Reactiveness	-0.281	0.779	Test > Control
Self Motivation	-0.890	0.374	Test > Control
Likability	-0.714	0.475	Test > Control

Table 5: Wilcoxon signed rank results per factor including z-score, p-value and the direction of the difference.

4.2.2 QUALITATIVE DATA

In the semi-structured interview a large amount of qualitative data was collected. The users were directly asked their opinion on the believability and likability of the iCat. These results are given in Table 6.

The main reason given by the participants for why they thought the test iCat displayed more lifelike behaviour than the control version was that the iCat seemed to look around more (6 times) and in some cases (4) it was said to show more expression. The participants that had no preference mostly thought that both versions showed some lifelike behaviour. Most participants expressed no preference in liking for a particular iCat, but the most frequently reported reason for liking the control condition iCat more was that it seemed more attentive (3) to them. Participants that liked test condition iCat more mainly said that this was because it seemed more lively (3).

The participants also gave some common statements about the iCat and the experiment in general. Eight participants reported that the task was distracting them from paying attention to the iCat and five participants said that they "forgot" to notice the iCat during the first session because all their attention was focused on performing the task (this problem was also noted by

Question	Answers	Responses
Did you notice differences in the iCat between the two interactions are what were they?	Yes	13
	Little	4
	No	1
Which iCat do you think displayed more lifelike behavior and why?	Test condition iCat	8
	Control condition iCat	2
	No difference	8
Did you like one iCat more than the other and why?	Test condition iCat	4
	Control condition iCat	5
	No preference	9
What did you think of the application/task?	Positive response	18
	Negative response	0

Table 6: Answers given to the questions asked in the interview. Given answers of all users were tallied and are displayed below.

the experimenter who observed the experiment from the control room). Six participants noted that the iCat sometimes reacted slow after they told it their answer. Four participants said that the iCat made a lot of noise which reminded them that it was a robot. Only a single participant mentioned that the test condition iCat's eyes remained focused on him when the iCat nodded or shaked its head.

Because a large number of participants mentioned that they found the task somewhat demanding, we also investigated any order effect. We found that when analyzing the quantitative data samples by comparing a participants first session with the data from the second session that 20 items moved closer to significant values (i.e., had lower p-values). This indicates that the experiment suffers from a considerable order effect. When looking at the actual values, the answers given in the first session are more extreme (i.e., there is a tendency toward strongly agree or strongly disagree) than in the second session.

4.3 DISCUSSION

In this experiment the main question was whether the manipulation of the iCat's gaze behaviour results in an increased believability and/or likability. The main conclusion that can drawn from the results of the experiment is that the participants were unable to see significant differences between the two conditions. We believe this can be mainly attributed to the design of the experiment.

Because of the considerable order effect the differences between the two conditions is leveled out. The order effect is likely caused by the fact that participants were unfamiliar with the setup of the experiment. Because they were completely unaware of the kind of questions asked in the questionnaire *and* their focus was not primarily on the iCat, they did not know what to pay attention to during the first session. After answering the questionnaire they had some idea what to look for in the iCat but had little to compare it to because they had missed these things during the first session. During the interview participants did however report that they saw differences between the two iCats. It is probable that they could not exactly identify what the difference was. Introducing a "dummy" session before the two conditions in which participants perform a similar task and complete a similar questionnaire would likely help to reduce the effect the order of the conditions has on the results.

The fact that the iCat was more part of the setting of the experiment than part of the task is likely another reason as to why participants were unable to report significant differences. Because the multiple choice questions of the task were quite difficult a lot of the participant's attention, in both sessions, went toward answering these questions correctly (even though participants were specifically told that this was not so important and were asked to pay attention to the iCat). Additionally the differences between the two iCats were subtle. Both iCats displayed similar gaze behaviour but differed in the actual movement. For example, the head of the control condition iCat moved mostly at a constant speed as opposed to the simulated movements (varying speed)

in the test condition. Due to the possible lack of attention for the iCat the participants may not have specifically noticed this.

That two of four significant items (1 and 6) relate to personality factors shows that gaze is important with regards to how people perceive personality. But because one item is in favor of the control condition and the other of the test condition it is difficult to say how gaze behaviour relates to believability. To say more about this would require additional experiments that focus on the impact of gaze on specific personality discriminants.

The quantitative data shows little significant differences between the iCat with and without the gaze behaviour. But the fact that despite the considerable order effect there is a slight tendency toward more emotion, reactiveness, self motivation and likability in the test condition warrants further investigation into the effect of gaze behaviour on believability and likability. This is also reinforced by the qualitative data where nearly half the participant said that the test iCat showed more lifelike behaviour.

5   Conclusions an Future work

The main objective of this work was to increase the believability and likability of the iCat by designing a gaze behaviour system. We studied gaze behaviour from a number of perspectives to see what is required if such a system is to have an effect on the believability and likability of a character. We found that besides vision gaze has an expressive and functional purpose in social interaction; mainly conveying emotion and personality and mediating conversation flow. Also when applied to robots and virtual character gaze can portray reactiveness to the environment and self motivation.

We designed a gaze behaviour system that implements models for the four most important types of gaze behaviour in species with binocular foveated vision: vergence, vestibulo ocular reflex, gaze shifts and smooth pursuit. The models realistically simulate these types of gaze movements on the iCat. This was achieved by using models and empirically obtained data of gaze behaviour in humans and primates provided in literature. The gaze behaviour system can be used by application developers to create complex interaction scenarios for the iCat. The modular design of the system is such that the movement models are fairly independent of the embodiment. Because of this the system can be easily ported to other robotic platforms. The only requirements for these embodiments is that they have a head and eyes with two degrees of freedom.

The problem of measuring the effect of the gaze behaviours on believability and likability of the iCat was also tackled. Believability is a term often used in literature on virtual and robotic characters, but these lack a clear and common definition of the term. Additionally actual established measurement methods for believability seem to be non existent. Our approach was to take a number of attributes that make a character more believable and relate them to gaze behaviour. We found that personality, emotion, reactiveness and self motivation are influenced by gaze. The effect of the gaze behaviour on these four factors together with likability were tested in an experiment. We measured the effect of gaze behaviour on behaviours on believability by comparing quantitative and qualitative about the user's perception of an iCat with gaze behaviour to an iCat without gaze behaviour. The results did not yield any statistically significant results but do warrant further effort in this direction. We also gained some valuable insight into testing the effect of the type of gaze behaviours we created on the believability and likability of the iCat. In reflection the user test might have required more time than was available, but has none the less turned out to be very interesting a valuable learning experience.

Overall, this study is a step towards gaining more insight into gaze behaviours for robotic characters. We presented an approach to creating realistic models of gaze behaviour that can be further utilized to create a more socially competent iCat. We consider the observable gaze behaviour that has been designed for the iCat quite natural even though the user test does not fully confirm this.

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