EYE MOVEMENT & FACIAL EXPRESSION IN HUMAN-ROBOT COMMUNICATION

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ABSTRACT

As the interest in social robotics grows, we examine human-human communication to develop more comfortable and effective models of human-robot communication. Person to person communication incorporates both verbal and non-verbal communication channels to add expression and detail to communicative interactions. This work focuses on non-verbal facial expression, and head and eye movements. Recording of directed conversations between the experimenter and participants was performed. The analysis of the data reveals strong correlations between speech generation and facial non-verbal behaviour. Specifically, we look at the correlations between blinking and communicative behavior, as our results suggest that blinks have a communicative function to inform the speaker of the listener's mental communicative state. This has further led to the creation of a blink generation model for later inclusion into an overall anthropomorphic model of human facial behavioural characteristics within communication.

Keywords: *Human-Robot Interaction, Social Robotics, Eye Movement, Communication Modelling, Blink Modelling.*

1. INTRODUCTION

This study analyses human-to-human communication, specifically targeting facial behaviours and eye movement within one-to-one conversations. The analysed information from the study will be used to create a facial behaviour lexicon for use in the development of a computational facial communication model. The aim of the model is that it should seamlessly integrate into any robotic / video conferencing 'avatar' system as an integral part of their social communication interface, allowing a human user to both "stay in touch" with the system during communication and also understand the systems internal mental communicative state.

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As humanity moves ever deeper into the technological age, the creation of a social cognitive robot (i.e. a robot which resembles the bodily structure of a human, can communicate effectively utilising human socio-communication metaphors and still comfortably exist in human social surroundings) becomes increasingly obtainable. Research in this area is growing steadily, but we are still within the early stages and numerous problems remain to be solved [1] before the emergence of the first truly social cognitive robot. One of the greatest challenges herein is that of human social acceptance of this technology [2-5]. The creation of a social cognitive robot therefore encapsulates many disciplines, including Psychology, Physiology, Sociology, Human Computer Interaction (HCI) and Human Robot Interaction (HRI).

Sociological studies have revealed great interest in the idea of owning / utilising a social robot, with the main uses that humans currently require from their social robots being: 35% Housework, 20% Food Preparation and 11% Personal Service [6]. Further, there is also a growing need for the development of welfare robots for use in caring for the growing elderly population [7].

It is generally accepted that any useful social cognitive robot will need to be able to effectively communicate with its users [3, 8]. Humans use both verbal and non-verbal (head and eye motion, gesture and pose) modes of communication to enable effective social communication. Eye contact and facial expression are especially strong non-verbal elements within human communication [9], allowing for detailed control and feedback within the communicative act [10, 11]. Eye gaze is used as both an instigator and as a grounding mechanism (e.g. interest holding and turn-taking behaviours) throughout conversation [12], producing such detailed grounding feedback that conversational dynamics are able to be changed in real-time [13]. This allows for subtle updates in communication, such as understanding [14], mood, acceptance, hierarchy, noise level filtering, expressiveness and focus of attention [15].

Fischer [16] has explored emotion with respect to pure language, showing that emotional speech can pose many problems if not understood by the robotic system and further, that the more emotive responses seem to require more face-to-face communication, with deliberate eye contact required to ascertain these subtle emotive cues.

Research has been performed on eye gaze with both humanoid avatars and robotic systems showing that random gaze does not improve communication, but that directed gaze that reacts based upon the conversation dialogue dramatically improves human-robot communication [13, 17, 18].

Research has also been performed that shows the main areas of focus of gaze on the face of the interlocutor within conversation, with the eyes and mouth being the most dominant target zones. It is concluded that when listening, the mouth is commonly viewed to benefit from lip reading and whilst speaking the eye area is more commonly fixated for emotional and conversational grounding cues [19].

For robots to exist within the human social space they will need to interact seamlessly with humans. Humans are experts in social interaction, and thus their expectations of a robot's communicative interactions will be extremely high. It seems pragmatic therefore to imbue these social robots with imitative human communication systems [20, 21]. These systems will allow the robot to monitor and interpret human behaviour and to communicate naturally based upon this input data, balancing the robot's capabilities with the human expectation of a 'social cognitive robot'. Due to this high level of complexity within human communication, reaching an acceptable level of model functionality will be extremely important in satisfying the human interlocutor's conceptual model of human social interaction.

As a further step in the creation of this complex communication system, we are proposing the development of a computational facial communication model, specifically enabling a robot to express mental states of thought, understanding, unsure understanding and misunderstanding.

This paper details our initial research into the formulation of this model, through the review of our first experiment which looks at facial expression and eye movement within real human-human communication, utilising pre-developed dialogue scripts that elicit the required Mental Communicative States within the experiment participants. Further, our initial data analysis has focussed strongly on the correlations of communication behaviours against the non-verbal facial action of blinking, finding them to be strongly correlated, which is in agreement with previous research findings showing increased blinks during speaking and links to saccadic eye movement [19, 22, 23]. This has led to the creation of an initial blink model (See section 3.4, Figure. 8).

2. METHOD

2.1. Participants

Participant's conversations and facial movements were recorded to high-definition (HD) video for post-experiment analysis. Instructions were given to each participant prior to the beginning of the experiment and they then decided whether they still wished to participate in the study. No instructions were given on communication behaviour such that participants would then act naturally during the communication interactions. All participants were male students from the University of Plymouth. Each was identified for the purposes of the experiment by a pre-generated participant number and their self-reported age and gender. A total of six participants took part in the experiment.

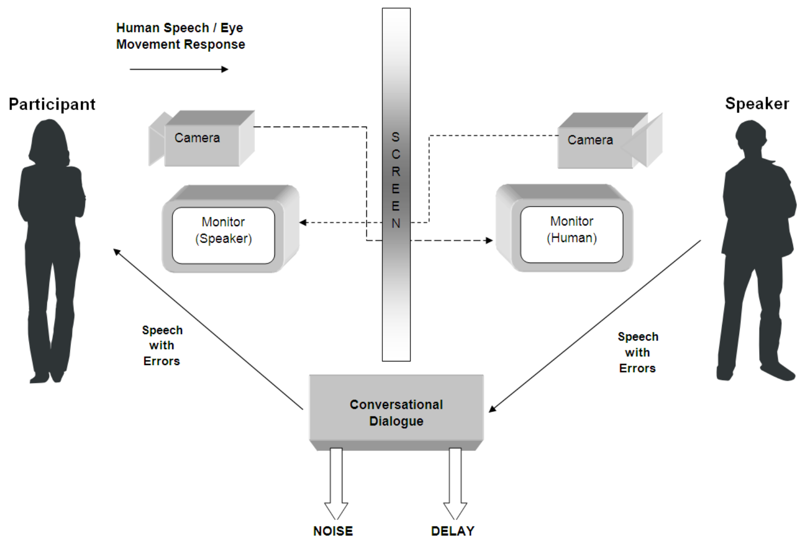

Figure 1: Experimental Design

2.2. Procedure

Two laptop PC's and four cameras were used in the experiment setup (Figures. 1 and 2). Two HD camcorders and two webcams were each attached to one of the laptop PC's. The webcams were used to display an image of the speaker and participants faces to each other on the PC screen placed in front of them. The HD camcorders were used to record the voice and facial movements of both the participant and speaker for post-experiment analysis. A separating panel prevented a direct visual contact between speaker and participant. This allowed for a 'visual denial of speaker' scenario as well as focusing behavioural responses purely on facial behaviour as opposed to complete non-verbal body language, such as hand gestures.

Figure 2: Experimental Setup

Figure 3: Mental Communicative States
(Clockwise from top left: thought, understanding, misunderstanding, unsure)

Four dialogue scripts were created to elicit the required Mental Communicative State responses from the participants. Each script utilised a different style of questioning and noise (e.g. fake words, incorrect words, silence, visual denial of speaker) based communication positioning (Table. 1) allowing monitoring of human facial communication behaviour within understanding, unsure understanding, misunderstanding and thought mental communicative states.

Facial video data from the conversations was captured to AVI video file (including the dialogue audio stream) and the participant's facial behaviours transcribed. The Mental Communicative States of (Figure. 3 - clockwise from top left) thought, understanding, misunderstanding and unsure understanding were derived based upon my own interpretations of the participant's verbal and facial behaviours (see Section 2.3 VII).

Table 1: Dialogue Stimuli

Dialogue	Description
1	This is a strongly conversational script which derives heightened emotional links from the participant towards the speaker through emotion based question content. This may derive results that show differences in eye movement behaviour between emotive and non-emotive dialogue. Dialogue errors are interspersed at the end of the conversation so that confusion should not affect participant responses through the bulk of the conversational interaction.
2	This is a knowledge question based script that is intended to heighten the differences in eye movement behaviour between immediate thought → understanding and longer term thought → misunderstanding → understanding responses. Errors in the dialogue are blocked at the beginning of the conversation such that confusion may be seen to affect the participant's responses throughout the main bulk of the conversational interaction.
3 / 4	These are a mixture of emotive and knowledge based question content. This may derive results that show changes between emotive and non-emotive eye movement behaviour. Errors in the dialogue are interspersed throughout the dialogue. This may derive results that show changes between confusion and non-confusion states and their associated eye movement behaviours. Script four is also performed with visual denial of speaker to elicit any differences in behaviour pertaining to verbal only communication.

2.3. Data Analysis

Human social interaction is a complex system and this shows explicitly in facial behaviour within communication, with subtle movement and interaction between verbal and multiple non-verbal facial behavioural dimensions:

I) Speaker / Participant Utterances (sSpeech / pSpeech)

Conversational dialogue between the speaker and the participant, based upon the dialogue scripts.

II) Eye Movement (PEM)

All visible participant eye movements, specifically those for gathering information (i.e. looking at the face of the speaker) and those used in the process of thought (i.e. looking up-left or up-right whilst processing a response utterance).

III) Eye Gaze (PEG)

Direction of gaze, either at the interlocutors face (ATF) or away from the interlocutors face (AWF).

IV) Head Movement (PHG)

All visible participant head movements including nodding, shaking of the head and gaze following.

V) Eye Blink (PBL)

Participants eye 'blink' actions.

VI) Facial Expression (PFE)

Communicative expressions made by the face. We have so far found four main facial expressions within our data analysis process, these being the smile (happiness / understanding / agreement), pursed lips (thought, unsure understanding), furrowed brow (questioning / misunderstanding) and raised brows (thought).

VII) Mental Communicative State (PCO)

Four derived Mental Communicative States from all verbal and non-verbal facial behaviour throughout a dialogue: Thought (T), Understanding (U), Unsure Understanding (UU) and Misunderstanding (M).

VIII) Stare (PST)

Participant's saccadic eye movement is inhibited: no eye movement / apparent scene processing.

An XML script (Figure. 4) was created for transcription to enable encapsulation of these dimensions over time, building a detailed corpus of the participant's facial behaviours.

```
<dialogue xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="script_template.xsd" participant="" script="">
        // Participant / Speaker Utterances
        <sSpeech startTime="" endTime=""></sSpeech>
        <pSpeech startTime="" endTime=""></pSpeech>
        // Participant Eye Movements
        <pem startTime="" endTime="">
                <pems startIndex="-" startTime="" endTime="" angle="" distance="" />
        </pem>
        // Participant Eye Gaze
        <peg startTime="" endTime="" Looking="" />
        // Participant Head Movements
        <phg startTime="" endTime="">
                <phgs startIndex="" startTime="" endTime="" direction="" distance="" endAngle="" />
        </phg>
        // Participant Blink
        <pbl startTime="" endTime="" />
        // Participant Facial Expression
        <pfe startTime="" endTime="" Expression="" />
        // Participant Cognitive State
        <pco startTime="" endTime="" State="" />
        // Participant Stare
        <pst startTime="" endTime="" />
</dialogue>
```

Figure 4: XML Mark-up – Facial Communication Encapsulation XML (FaceML)

Prior XML scripts have been created such as 'HumanML' (Human Mark-up Language) and MURML (Multimodal Utterance Representation Mark-up Language) [24, 25], but these were unsuitable for encapsulating all of the elements of the behavioural characteristics that we wished to annotate, therefore we created our own XML script and schema entitled 'FaceML' (Facial ACtion Encoding Markup Language) for this purpose. The analysis process initially transcribes the data from the AVI videos of participant / speaker interactions based along the behavioural dimensions (Section 2.3) using the 'FaceML' markup language, and then converted to CSV file format through a C# based text parser, producing the following temporal timeline output (Figure. 5) within Microsoft Excel.

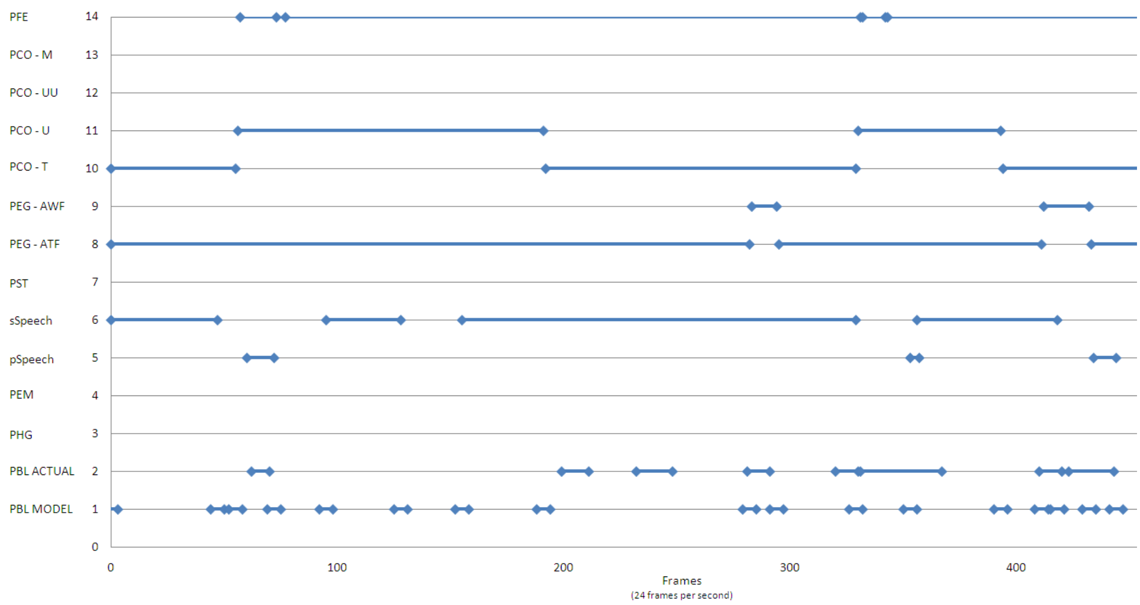

Figure 5: Temporal Data from Participant XML Transcription *(see 2.3 for symbols)*

The temporal timeline output was then analysed with respect to significant non-verbal facial behaviour dimension co-occurrence (i.e. co-occurrence percentiles above 60%).

3. RESULTS

3.1. Blinking as a measure of Utterance and Mental Communicative State

A number of strong correlations were found between participants conversational behaviours within processes of thought and utterance instigation. Our initial analysis has focussed strongly on blinks as we have found these actions to regularly co-occur (i.e. the blink action overlaps either the onset or offset) at the instigation of changes in mental state within communication (Table. 2), where most blinks appear to be correlated with other facial behaviours and conversational events.

For example, Figure 5. shows all participant blinks (PBL-ACTUAL), bar one, occurring at the same time as either the start of speech of the participant (pSpeech), the start of a thought process (PCO-T), the start of looking away from the speakers face (PEG-AWF), the end of participant speech (pSpeech) and/or the end of speaker speech (sSpeech). These events ultimately all reveal changes in the mental state of the listener. Table 2 indicates the rate of co-occurrence of blinks with various indicators of change in mental states. These results suggest that blinks have a, often involuntary, communicative function, informing the speaker of the changes in listener's mental communicative state.

Table 2: Percentage of onsets/offsets having a co-occurring blink

Conversational Behaviour	Blink Co-Occurrence
Speaker Speech (sSpeech) Onset / Offset	42% †
Participant Speech (pSpeech) Onset / Offset	69%
Mental Communicative State (PCO) Onset / Offset	71%

Figures 6 and 7 show snapshots of these blink correlations in action within participant data.

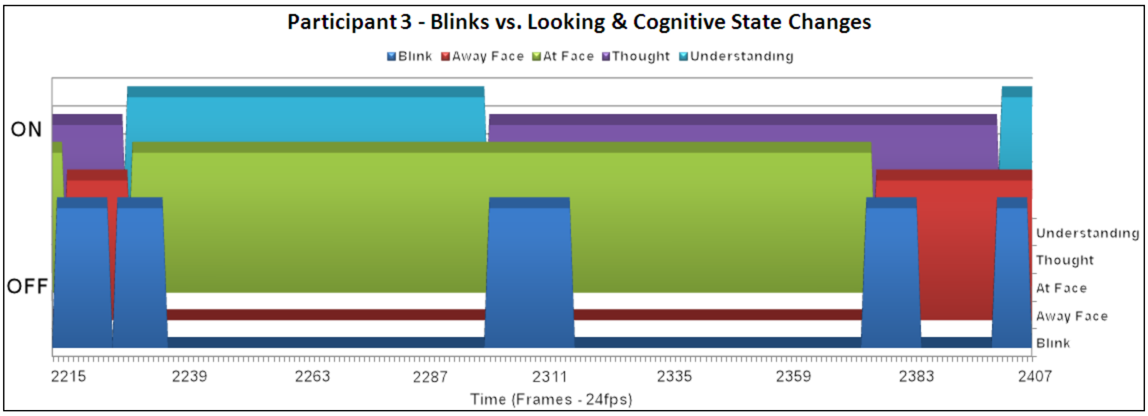

Figure 6: Blinks relating to Looking away from Face and Mental Communicative State Change

Figure 6 shows Participant 3 looking at and away from the speakers face during Mental Communicative State changes between "thought" and "understanding". Blinks in this instance correlate well with the onset/offset transitions of the state and looking directions.

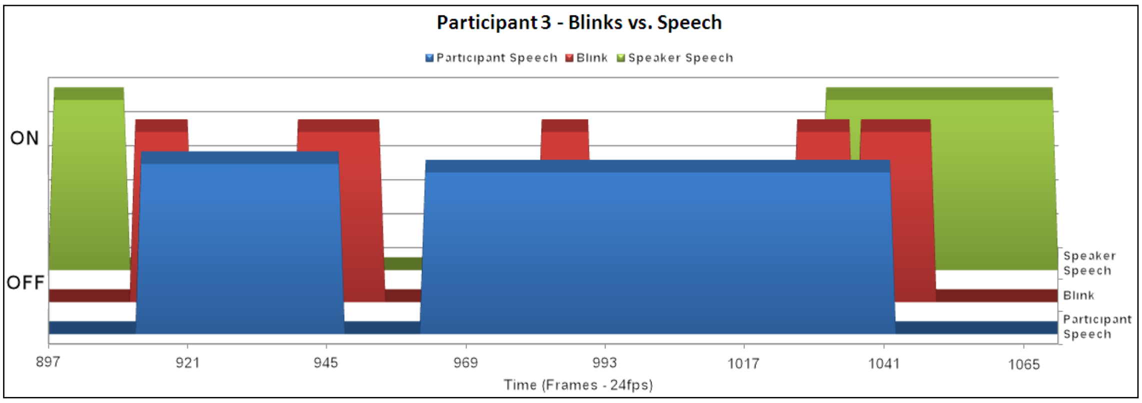

Figure 7: Blinks relating to Utterance Behaviour Timings

† The lower value of Speaker Speech is likely due to human processing times as we are not exactly sure when a speaker is going to start or finish speaking, thus we need to widen the catchment (i.e. +/- ¼ second) of blink co-occurrence around these behaviour onset/offsets.

Figure 7 shows Participant 3's blink actions based upon their own and the speaker's utterances. Strong correlations between utterance onset/offset are displayed. Two anomalies are displayed however; the first is that the second participant utterance onset is not covered by a blink action and the second is that the third blink is not related to a behaviour onset/offset (discussed later in Section 4).

Table 3: Blink / Facial Behaviour Co-Occurrence

	Participant 3	Participant 5	Participant 6
Total Participant Blinks	*136*	*123*	*122*
Participant Blinks not relating to a State Change	*47*	*72*	*50*
Blink / Facial Behaviour Co-Occurrence	*65%*	*41%*	*59%*

Table 3 shows the fraction of all blinks that are co-occurring (or not) with identifiable mental state changes. On average, 55% of participants blinks co-occur with facial behaviours indicating mental state changes.

3.2. Individual Variability (and Model Control)

Individual participant's numbers of overall facial movements were extremely variable, however, the meaning conveyed within a conversation was still similar and the same social communication effects were experienced in terms of overall conversational instigation and grounding (i.e. Participants varied in the number of blinks performed within, and length of time to complete a dialogue, however initiating conversation and smooth turn-taking therein were never affected by these differences). It seems likely that facial expression generation of low complexity could therefore be produced where the same amount of Degrees of Freedom would be necessary, but the amount of facial movements required to conform to human social expectations could be reduced to a core base level of expression. There is also a strong possibility that varying this level of expression would allow for the increase / decrease of expressed contextual emotion within a conversational interaction, greatly increasing socio-behavioural properties.

3.3. Blink Generation Model

Based on our hypothesis (Section 3.1) that blinks have a communicative role, it would be possible to build a conversational robot with blinking behaviour that might inform its user of its internal mental communication state in a way that taps into natural human communication mechanisms. Thus, based on our results, a blink model was derived (Figure. 8) which instantiates a blink action whenever a mental state change (Table. 4) occurs. (NOTE: The 'mental states' were derived by ourselves based upon behavioural analysis of three participants)

In the proposed model, the generated blinks are randomly placed within a ½ second interval of the actual mental state change onset / offset occurrence, thus 100% of behaviour onset / offset occurrences co-occur with a blink action. We also added a physiological blink mechanism, which commonly occurs 2.4 - 5 seconds where no blink has previously occurred [26-28].

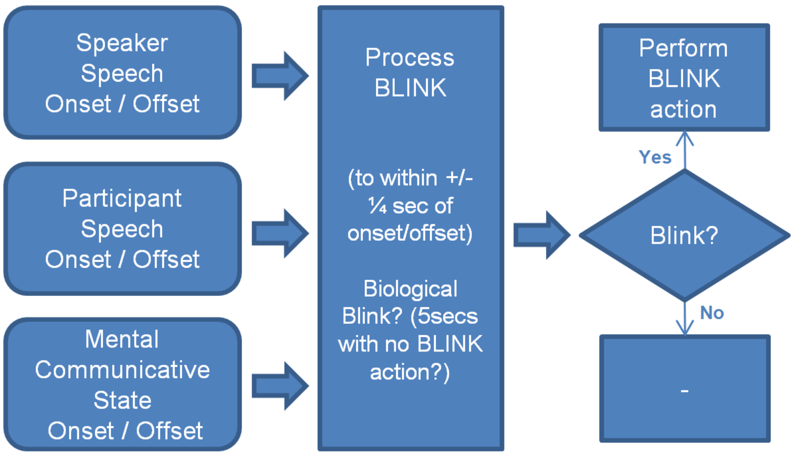

Figure 8: Blink Model Flow Diagram

Table 4: Mental State Changes expressed by blinks in recorded data

Mental Communicative State	State Change Indicators
Speech Recognition	Speaker Speech Onset / Offset
Speaking	Participant Speech Onset / Offset
Thought	Eye Gaze (away from / towards face)

The three mental communicative states that we can infer from the data are: (Table 4)

I) Speech Recognition

Participants tended to blink at the beginning of an interlocutors speech, as well as turn towards the interlocutor and fix their gaze them to show they were listening, keeping the conversation grounded.

II) Speaking

Participants tended to blink at the beginning of their own speech, signalling a state change from thought (to understanding, unsure understanding or misunderstanding).

III) Thought

Participants tended to blink at the beginning of a thought process, turning their gaze away from the face of the interlocutor to ground the conversation, showing them that they were not attending to them.

This model is reasonably accurate at predicting human blinks in its current state, mostly generating blink actions at the same time as participants when driven by the experimental mental communicative state indicators (see PBL-MODEL in Figure 5). However, (i) *the model tends to generate more blinks than actually performed by the human* and (ii) *the model does not account for the human blinks not associated with a defined state change*. These issues will be discussed further in Section 4.

4. DISCUSSION

Feedback from a robot, even to the extent of it allowing a user to "know" that it is processing information [29] is an important, but also extremely complex endeavour, but how complex does this model actually need to be to fulfil the requirement of a human conceptual model of social interaction. Our results suggest that there are many tiers in face-to-face human conversational interaction. These could be based around dialogue context and / or the emotional state of the conversant at the time of the interaction. Further work is required to clarify these layers beyond the blink model. (For example, further analyses of eye and head movements with respect to Mental Communicative States are expected to show a correlation between speed and distance of these motions and the complexity of the context within the response utterance and further, when expressing disagreement, the mouth is expected to add further expression by displaying in either an equilibrium or down-turned position).

Also of importance to this study, prior research has shown that blinks are highly correlated to eye movement saccades and central pre-motor brainstem activity [22, 23], also, our analysis data concurs with Raidt et al (2007) that blink rates are raised during speaking [19].

The proposed blink generation model is also in need of further analysis with respect to the two main anomalous areas highlighted: (i) The model at present generates a blink action at each behavioural dimension onset / offset (i.e. 100% co-occurrence) which is more than experimentally observed (Table. 2) therefore, the model instantiates more blinks than are actually performed by the human, it is likely that the human conversational system is inhibiting the blink behaviour, for example when the human speaks but their sentence is within the same context as the previous sentence (e.g. misunderstanding phrase to understanding phrase). (ii) Where the model does not account for the human blinks not associated with state change indicators (Table. 4), it seems likely we are missing certain extra behavioural dimensions that need bringing to light through further data analysis, including conversational analysis.

Initial improvements could be made to the proposed model (affecting failure area (ii)) by incorporating the physiological blink mechanism, the +/- ¼ second leeway for human response and processing time with respect to Speaker Speech Onset/Offset and also, the inclusion of a humanistic weighting to the blink occurrence within the model (Table 2). Adding these extras will not necessarily improve the model accuracy, but will likely improve its overall human socio-behavioural response feedback.

5. CONCLUSION

The analysis of human-human conversations is leading to the findings of links between eye movement and other facial behaviours in social interaction, as well as strong recurring behavioural traits within conversational interlocutors. Our results suggest that blinks have a communicative function, informing the speaker of the listener's mental communicative state. Thus our first step; the creation of an initial blink generation model is shown to have reasonable levels of correlation to human communication behaviours, specifically with respect to participant utterances and defined mental communicative states.

6. FURTHER WORK

Further work is required to complete the analysis of the corpus and with this, the mapping of a complete model of human facial behaviours within communication for use in the definition of a complex computational facial communication system.

Time-permitting, this experiment will be extended to use a greater and more diverse age and gender participant sample. This will lend more robustness to the validation of our derived Mental Communicative State (Thought (T), Understanding (U), Unsure Understanding (UU) and Misunderstanding (M)) change mapping process and facial behavioural actions linked to speech context.

Our next step is to implement the blink model within the 'iCub' robotic platform utilising the 'lightbot player' animation system [30] and its effectiveness will be gauged through user based testing experiments.

Further, a system of conversational grounding (as discussed in Section 1, Paragraph 4), will be implemented to surround the model, performing methods of conversational instigation, completion, interest holding and turn-taking.

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