Analyses of Feedback in HRI

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***Abstract*— Feedback is one of the crucial components of dialogue which allows the interlocutors to align their internal states and assessments of the ongoing communication. Yet, due to technical limitations, immediate and adequate feedback is still a challenge in artificial systems and, therefore, causes manifold problems in human-robot interactions (HRI). Our starting point is the assumption that the manner and content of the feedback, that robots currently are able to provide, often disturbs the flow of communication and that such disruptions may impact the affective evaluation of the users towards the robot. In our study we therefore analysed quantatively how different feedback behavior of the robot resulted in different affective evaluations. In a subsequent qualitative analysis we looked at how the different feedbacks actually affected the communicational flow in detail and produced hypotheses on how this might influence the interaction and thus the affective evaluation. Based on these analyses we conclude with hypotheses about the implications for the design of feedback.**

I. Introduction

One central assumption in social robotics states that if users are to accept robots in their private lives, robots need to blend in the social situation and act according to social rules. This means that embedded in social situations, a robot is not only situated in an environment with humans and can interact with the other agents [1], but is also designed to respect the rules of dialogue. The first ability, to blend in the social situation, is known as ”social embeddedness” [2], while the second ability, to respect the rules of dialogue, is also referred to as ”interaction awareness” [1]). Yet, in a natural interaction, the two abilities are interweaved: If a robot respects the rules of a dialogue, it will more likely be embedded in social situation; a socially embedded robot has to act according to ”human interactional structures” [1]. A phenomenon that combines the two aspects in an natural interaction is feedback. Feedback is a response signaling an immediate result in the environment which in turn can be used as a basis for another more adapted behavior. This way, a basic pattern of interaction depending upon mutual monitoring can emerge and creates a social interaction (cf. [3]). In our approach, we pursued the question of which factors may be crucial for the two central abilities of a social robot, social embeddedness and interaction awareness, and how they can be used to design feedback undesirable for a successful communication.

To design a robot that is able to blend in a social situation, factors like anthropomorphism [4], [5] and perceived personality [6] have been discussed. In our study, we accessed the quantitative correlations between the robot’s behavior and the user’s reaction by asking how users perceive the personality of a robot they have been interacting with in a non-restricted situation. The underlying scenario for which our robot is designed mainly consists of showing and explaining locations and objects to a robot in a home-like environment. The goal is to teach the robot enough knowledge in order to enable it to autonomously navigate to perform fetch and carry jobs or basic object manipulation tasks such as laying out the table. In such a scenario, the initiative is mainly with the user, however the degree of initiative taking of the robot may vary and thus be used as a cue to convey different robot personalities or may otherwise affect the users’ evaluation of the robot. In our study, we varied initiative taking behavior of the robot and analyzed the effects this had on the users’ perception. In detail, we addressed the following three questions: (1) If asked to describe a robot’s personality with traits established in personality psychology, how easy do users find this task and how sure are they about their judgment? (2) Does the robot’s initiative taking behavior influence the perceived personality? (3) Which factors are relevant for the affective evaluation of the robot?

Based on these results, we attempted to explain how can a robot act according to social rules. In our approach, we applied these quantitative findings to qualitative analyses based on methods derived from sociology. We assessed the situative factors of the communication by applying ethnomethodological conversation analysis to each interaction and by characterizing the given feedback by evaluating users strategies and difficulties in keeping the communication in its flow. Pursuant to social constructionism, individuals actively participate in the creation of their perceived reality. Accordingly, social situations consist of mutual processes of attribution and the ascription of meaning. That there is to be some kind of feedback, is part of the actors expectancy of communication settings. If there is not, the expected indicator is not given and hinders the follow up. We reveal strategies of users’ elaborations that substantiate social expectation in communicative processes. These identified basic interaction patterns in HRI seem to be close to social communication practices in human-human settings.

Our results demonstrate the synergetic effects of the com-

bination of quantitative and qualitative analysis: the combined analysis allows us to formulate hypotheses as to why users rate the robot and its interaction in a certain way. In detail, we present hypotheses on what situative and personal factors influence the interaction and what kind of feedback is necessary for a successful complex human-robot interaction.

II. The Robot System

The basis of our data collection is a user study carried out with our mobile robot BIRON [7] (Bielefeld Robot Companion), an interactive robot based on an ActiveMedia PeopleBot platform. This robot is able to carry out multi-modal interactions with a user fully autonmously. The main component is a person attention system [8] which enables the robot to focus its attention on a person. Based on this attention system the robot can physically follow the person of interest and engage in verbal interactions. A multi-modal object attention module allows the system to learn new objects shown by the user. The verbal interactions are carried out by a dialog component [9] that enables mixed-initiative interactions. For the purpose of this study we disabled BIRON's mobility so that it remained fixed on its place. Note that the complete software also runs on our anthropomrophic robot BARTHOC [10] where further interaction capabilities such as facial expressions are currently being integrated. However, at the time of the study the running system was only available for the mobile robot BIRON.

The different initiative behaviors of BIRON are realized by the dialog system. In contrast to many finite-state based dialog systems for robots ([11]–[13]) we implemented a powerful computational model of multi-modal grounding [14] which is based on the grounding idea of Clark [15] and extends the conventional computational grounding models of Traum et al. [16] and Cahn et al. [17].

For the personality study we implemented two dialog modes for BIRON (a high-initiative mode and a low-initiative mode) that differ from each other in whether or not the robot initiates the interaction with the user and makes comments on the ongoing interaction based on its evaluation of the communicative success as shown in Table I. Figure 1 presents a dialog example from a user interaction with the high-initiative version of BIRON. In Ex1, BIRON actively greets a person once it detects her and in Ex6 it makes remarks on its own poor performance. The low-initiative BIRON does not have these two capabilities. The technical realization of them is described in detail in [9].

III. Data Collection

For the data collection we used a between-subject design with a total of 14 users aged between 25 and 37 years interacting with BIRON. Each subject had to go through two subsequent interaction sessions. In the first warm-up session the users were asked to familiarize themselves with the robot by asking questions about its capabilities upon which the robot would give a short explanation ("You can show me objects and locations") and the users would start showing objects. Before the second session the users were given more technical

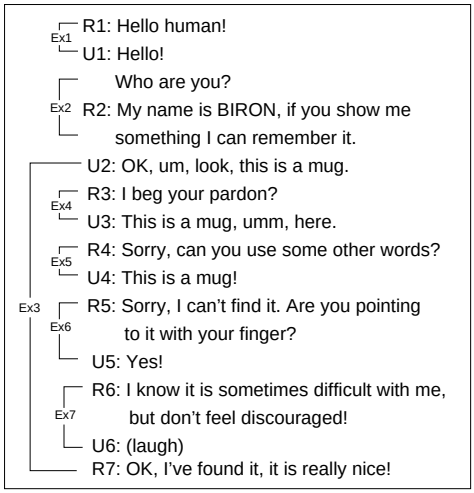

Fig. 1. Taking initiatives (Ex: exchange, U: user, R: robot)

information about the details of the underlying functionality in order to minimize technical failures which can occur when users do not stand still or do not look into the robot's camera while speaking etc. These instructions were intended to help to reduce perception errors of the system and to make users feel more comfortable during the interaction. Then the subjects were given the instruction to show specific objects to the robot. The mean interaction time of each session was about 10 minutes, yielding an overall interaction time of about 20 minutes per subject. After the second session the users completed a set of questionnaires regarding their judgment of the interaction as well as ratings of the perceived personality of the robot, of their own personality and on how much they liked the robot. The personality of the robot and the user were each assessed by a time-economic questionnaire, the BFI-10 [18], which measures personality according to the widely accepted and cross-culturally [19] as well as more or less even cross-speciesly [20] applicable Big Five Model of personality [21]. Furthermore after rating the robot's personality users were asked how easy the task of judging BIRON's personality was and how sure they felt about their judgement. Each of these questions was answered by a 5-point verbal rating scale with 'very easy' / 'very sure' and 'very difficult' / 'not sure at all' as the extreme anchor points. As an affective evaluation of the interaction users were asked if they liked BIRON, this question was to be answered with a simple 'yes' or 'no'.

For the qualitative analysis, the interactions were video taped and later analyzed in detail.

In order to assess the influence of different initiative-taking behaviors of the robot on its perceived personality we used two different interaction types of the dialog system that were randomly distributed over the subjects. In the low initiative interaction type the robot only gives feedback when addressed by the user. Only in case of errors the robot takes the initiative and reports them to the user. In contrast, the pro-active interaction type will actively engage in a conversation by issuing a greeting when it detects a person facing the robot. It will also

Feedback in case of..	High Init.	Low Init.
User command	+	+
User query	+	+
Error messages from system	+	+
Seeing human	+	-
Well going interaction	+	-
Badly going interaction	+	-

TABLE I

FEEDBACK BEHAVIOR OF SYSTEM WITH HIGH INITIATIVE ('HIGH INIT.') VS SYSTEM WITH LOW INITIATIVE ('LOW INIT.')

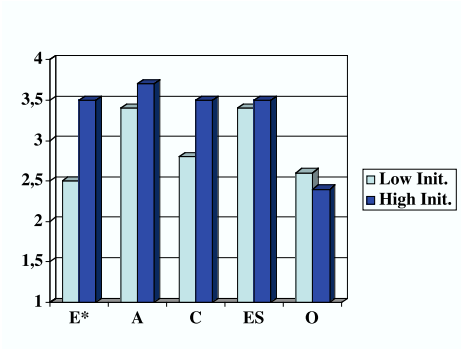

Fig. 2. Personality ratings of users interacting with robot with high vs. low initiative interaction behavior. Star marks significant difference between the two settings. (E: Extraversion, A: Agreeableness, C: Conscientiousness, ES: Emotional Stability, O: Openness to Experience)

give comments relating to the success of the communication at certain points during the interaction (e.g. "It's really fun doing interaction with you" or "I know it's sometimes difficult with me, but please don't feel discouraged"). Note that in contrast to other studies on the perception of artifical agent's personality we use an interactive cue that is not pre-programmed but depends on the actual interaction situation and thus takes the user in the loop as an active interaction partner into account.

IV. QUANTITATIVE STUDY ON PERSONALITY

In this section we report on some quantitative findings from the questionnaire study on the perceived personality of BIRON. In general the subjects reported to feel 'very sure' (71.4%) about their judgements concerning BIRON's personality. Also, most of them (57.1%) thought the task of answering the personality items was 'very easy' or 'rather easy'.

Users interacting with the pro-active interaction type of BIRON rated the robot significantly higher on extraversion than users interacting with the low initiative version (*t*-test for independent samples: $p < .05$, see Fig. 2). Interestingly, the pro-active version of the robot might also provoke more heterogenous personality judgments than the less initiative version. The standard deviations of the ratings of the robot's personality traits were larger by 1.11 to 3.02 times in the user group interacting with the more initiative version than in the user group interacting with the less initiative version of BIRON.

The third research question we addressed was, which factors might influence the affective evaluation of the users concerning BIRON. Overall 57.1% of the users answered that they liked BIRON. Most interestingly it turned out that in the group of users interacting with the pro-active version of BIRON 85.5% liked the robot, while this was only the case for 28.6% of the users interacting with the less initiative version. The correlation of $r = .577$ ($p < .05$) indicates that 33.3% of the variance in the users' answers concerning this question could be explained by the root's interaction behavior. In short, there was a significant and strong tendency of the pro-active version being preferred by the users over the less initiative version.

However, while this quantitative analysis provides us with a good basis for statistical correlations it can not answer the question *why* users tend to prefer the extroverted behavior. Thus, in order to produce more concrete hypotheses about this question we performed a qualitative analysis of the interactions which is described in the following section.

V. QUALITATIVE ANALYSIS OF FEEDBACK IN HRI

Our basic assumption is that users will prefer a robot when they perceive its behaviour as social. But what does it mean for a robot to act according to social rules? In order to concretize the social phenomena and special character of an interaction situation and to explicitly frame the constraints and context of information given, we analyzed interactions with BIRON from a sociological point of view. As methodological approach we employed ethnomethodological conversation analysis techniques. The empirical case study is presented in the following section where some findings and also interpretations are given.

We apply the social constructionism and Niklas Luhmanns systems theory as theoretical frame for HRI in a sociological perspective. There, communication is seen as the central vehicle establishing social relations. But how do people act in the face of a non-human interaction partner? How do people adjust their interaction in these specific human-robot settings? Do they establish relevant patterns of behavior? The focused phenomenon chosen for our analysis upon HRI is the variability of *feedback*. Our case studies bring to light that the users interprete the context and syntonize their performances according to their interpretation of the situation.

A. Theoretical Framing - Constructionism and Systems Theory

The paradigm of social constructionism (a theory of knowledge) as developed in the 1960s (e.g. [22]), anticipates that there is not *one* single and true reality, but the world consists of subjective constructions of the perceived phenomena made by subjects. According to this, dealing with *reality* means that the individual always refers to its own perceptions (which evidently differ from each other). From this follows for interactions that the interpretations of the communicating partner's actions and his decisions that keep the conversation going are context-driven, situative and individual.

1) Constructionist Prerequisites: From the perspective of the social constructionism, a situation is built up in a human's mind from variables as context, knowledge and the ascription of meaning (e.g. the specific cultural background). Thus, social reality is a dynamical construction made and renewed by practical acting. As such, each action has to be understood as communication practice and, vice versa, communicating is a constructive action.

2) Systems of Communication: The sociologist Niklas Luhmann's systems theory describes the functional differenciation of society. In these terms, modern societies build up a web of distributed functionalities [23]. A social system's main function is to lead and organize interactions. Accordingly, the main operation is the attempt to *understand* the other's communicative distributions, and to assign some discourse elements as well. This operation is much more complex, than it might appear. Communication consists of the triad information, message and understanding [23]. Which means that it is not evident to access a simple transfer of facts but a communication consists of the longing for 'accessibility' in several dimensions.

3) Systems of Interaction: A social system according to Luhmann is built on coordinated actions of several persons [24]. Because social systems can be characterized mainly by their communicative procedure [23], social systems are systems of communication. While action is constituted by processes of attribution, cognition has a high impact on interaction proceedings.

B. Adapting Sociological Systems Theory to HRI

In this paper we discuss feedback as a problem of expectation. Drawing decisions about the next action is a kind of selection which refers to former action-decision settings. Concrete actions reduce the complexity of all possible actions by means of attribution and expectation. Generalizing the own intentions leads to expectations that lower the world's complexity: if to my thoughs, there is only one possibility to behave, I can await its appearance and in any other case, decline all not expected operations. The interaction itself is an operation of registering the operations of others and comparing them to one's own suggestions which leads to concrete decision taking and further actions. Systems of interaction are interrelating constructions driven by expectance and estimation. HRI deals with the overall problem of communication in a specific context. The reciprocal setting of interrelated expectations differs from a sheer humanoid interaction where both partners tend to interprete the other's actions flexibly. In case of interacting with a robot, we have to ask what is *social* about the situation and what is special in the human's behaviour? The general strategy in lowering the costs of interacting in HRI is to implement dialogue strategies that match human speech behavior as much as possible. Feedback plays an important role in the attempt of understanding as it serves as checkback signal for both counterparts. Since strategies of interaction are revealing social expectation in communicative processes the aim is thus to establish and reestablish step-by-step access and connectivity. Based on this considerations, we focussed our analysis on feedback in the HRI experiments.

C. Qualitative Evaluation

1) Ethnomethodological Conversation Analysis: In contrast to the experimental setting described in IV., qualitative analysis is based on fine grained observations on the behavior [25]. The methodology refers directly to the observed and video taped interaction. Ethnomethodological conversation analysis is a technique acted out by the researcher him-/herself. Not the user's ratings about their own interactions were collected in a questionnaire, but their performances were reviewed and analyzed.

2) Hypotheses and Questions: Feedback serves as an interacting mechanism. There is a dynamic interplay between the user's feedback and BIRON's verbal behavior. By studying the experimental setting qualitatively, we analyzed how users react, if the assigned reaction is not the expected one, or if the robot shows no feedback at all.

D. Results of Qualitative Analysis of Feedback in HRI

Due to the qualitative researcher's intention in studying *concrete* interaction proceedings in daily life, we analyzed the users' communicative behavior in its situative context. We found a huge variability of human behavior in HRI with BIRON. Several fixed phenomena consist of verbal variations, mimic assertions or rhetorical comments. The human users are referring to both, sensorial perceived utterances and conceptual ones, like their own expectations.

Based on the user's reactions BIRON's feedback can be interpreted either as a matching or a mismatching reply. BIRON's denounced feedback did not fit in every situation with the user's expectance. But in each situation the user reacted *somehow*.

1) Matching and Mismatching Feedback: Users expect from an interaction situation an alternating interplay. This bilateral mechanism which includes the functionality of turn-taking ensures the flow of communication. So the distribution of any feedback from the robot mostly is registered positive and answered by the user. We differentiate the two cases of a "good" *matching* reply that is directing to the continuation of the interaction process, and a "bad" *mismatching* reply that leads to an interruption in the flow of communication.

In the following we define a matching reply as holding the line by answering somehow as expected, as the first example of an dialogue with BIRON underlines:

User 03: "Look here!"
BIRON: "Yes, I'm looking."
User 03: "This is a keyboard."
BIRON: "It's really interesting."

From the human user's point of view it is also expectable that BIRON would give some internal insights, so he reacts positive to a given problem report as shown in the following example:

User 13: “What can you do?”
BIRON: “I just understood you partially. What did you say?”
User 13: “What can you do?”
BIRON: “I can follow you to an other location and you can show me something.”
User 13: “Ok.”

Even if the robot does not give semantically correct feedback, users tend to reprise the dialogue if they get *any* feedback from the system as can be seen in the next example:

User 01: ‘Hello!”‘
BIRON: “Sorry, I can’t understand you. Maybe you can use some other words?”
User 01: “What can you do?”

We define an episode in our experiment as mismatching if the user’s expectation can not be linked to the robot’s statement hence the user can not answer the robot.

The user’s expectation is linked to an awaited reaction. A not expected comment from the robot can irritate the dialogue because the user does not wait for it and is not ready to interprete it. In mismatching cases in which BIRON did not produce feedback at all or was giving an unanticipated answer, the users showed individual reactions. They often expressed their open loop as verbal repeating of their previous assertions. This meant on the prosodic level, modifying their accentuation by emphasis of singular words or syllables, also slowed reechoing and even spelling have been shown. In some cases the user switched to a different vocal pitch. On the lexical level, some usage of synonyms or differing expressions took place. The users expressed on non-verbal level mimic variation, such as lifting the eyebrows or augmenting the general frequency of gesture usage. There has also been discursive feedback just like encouraging the robot (e.g. User 03: “Oh, come on! Talk to me please!”).

Also, the users were shifting to thematic cues in form of naming and commenting the robot’s mistakes as in the following dialogue example:

BIRON: ”I know it is sometimes difficult with me, but please don’t feel discouraged!”
User 03: “What choice do I have?”

Some contributions are made (e.g. User 03: “Please don’t tell me it’s my fault.”) and even suppositions about the internal state of the robot are not rare (e.g. User 02: “I suppose that he wishes to end the conversation with me!”).

Interestingly users also tried out an other variance: they shifted to a meta reflexive level by addressing the experimentator. They interrupted the mismatching HRI and established an interaction with a human communication partner to whom they are familiar with and the flow of communication retained - in this case with a different partner.

2) Missing of Feedback: We can learn much more about the problem of communication by looking at the critical cases: As most critical moment within those interactions with a robot we found a given order by the user, not being reacted to at all. More specifically, if the robot does no show any reaction, there is no access for slightly and effortless continuing the interaction. After Garfinkel [26], those moments show fruitful efforts in applying repairing strategies. If a communicative lack occurs, the human will be trying to provoke any reset of the former dialogue to gain new access to the communication. In those situations the human users have to improve the interaction and they have manifold possibilities: they might be awaiting even longer for the robot to answer - and most of them in our study already did. Others tended to evoke a new and better accessible interactional element. This would be an assertion, provoking some feedback. Some non-verbal cues like snipping the fingers or waveing were acted out too. In each case, even the mismatching trials, the act of communicating *continues*, even if the interaction with the robot is cut off finally.

These general replying mechanisms are leading to typical behavior people acted out in the experiment setting: The users reactions tend to continue the interaction and offer some renewal of accessibility. If some spoken instructions remain not-answered, the user is getting irritated. Irritation will be augmenting by its duration.

Feedback is a reciprocal mechanism of monitoring, interpreting and answering the interaction partners’ verbal, mimic and embodied expressions as well as actions. The users tend to obtain and retain orientation towards the robotic system.

VI. Conclusion

The quantitative results have shown that the likeability of the robot is significantly correlated to the robot’s interaction behavior with the more extrovert system being preferred over the less initiative one. This result can be interpreted from a sociological point of view that by giving more feedback, the robot provides more access to the user to re-enter the communication after it has been interrupted by a system failure. Thus, by excusing for a fault, the robot gives the user an opportunity to make sense of the communication again and, thereby, to answer.

In contrast to this positive feedback, the robot’s message “I’ve lost you” does not relate to the user’s own experience and thus does not provide access for the user to re-enter the conversation since it does not make sense to her. This means that the understanding and correct interpretation of feedback is closely related to the context that the conversation is taking place in.

From these findings we can draw some conclusions about the design of feedback: A criterion for feedback that contributes to successful communication is that it needs to produce accessibility in order to motivate the user to continue the communication even when in trouble. In contrast, feedback that does not produce accessiblity will demotivate the user because it can not be related to the user’s own world of experience and expectations in the concrete context.

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