

A dialog system for comparative user studies on robot verbal behavior

Shuyin Li, Britta Wrede, and Gerhard Sagerer
Applied Computer Science, Faculty of Technology
Bielefeld University, 33594 Bielefeld, Germany
Email: shuyinli, bwrede, sagerer@techfak.uni-bielefeld.de

Abstract—In domestic social robot systems the dialog system is often the main user interface. The verbal behavior of such a robot, therefore, plays crucial role in human-robot interaction. Comparative user studies on various verbal behaviors of a robot can effectively contribute to human-robot interaction research. In this paper we present a dialog system that can be easily configured to demonstrate different verbal, initiative-taking behaviors for a robot and, thus, can be used as a platform for such comparative user studies. The pilot study we conducted does not only provide strong evidence for this suitability, but also reveals benefits of comparative studies on a real robot in general.

I. INTRODUCTION

Robotics researchers are becoming increasingly interested in user-centered design issues of human-robot interaction (HRI). Especially for robots designed to work with non-professional users in home environments many comparative studies have been conducted to find out user perception of robots and user preferences. Goetz et al. [1] investigated the relevance of robot appearance and behavior to user acceptance; Woods et al. [2] studied the relationship between user personality and the perceived robot personality; Walters et al. [3] explored the socially acceptable spatial distance between human users and a robot. In such comparative studies the robots were mostly controlled by a Wizard of Oz (WoZ) remote controller. Other researchers are more interested in real robot testings to find out improvement potentials of the given system. Severinson et al. [4] discussed social aspects of HRI departing from their experience with a fetch-and-carry robot for a motion-impaired user in an office environment. Kanda et al. [5] reported their 2-weeks field study of two interactive humanoid robots with children. Both WoZ and real robot testing provide valuable insight into human behavior in HRI.

However, there is only few studies on effects of robots' verbal behavior, neither in form of WoZ nor real robot testing. Although in many WoZ studies speech is used to demonstrate the behavior to be investigated (e.g., [1] uses different dialog patterns to produce playful and serious robot behaviors that the authors intended to test), crucial verbal behavior issues like how and when the robot should take initiative, what the robot should say to produce certain effects are seldom the focus of the study in HRI. This does not mean, that these issues are not relevant. On the contrary, for many domestic social robots the dialog system is the main interface between the user and the robot. The robot verbal behavior

realized by a dialog system is explicit and clearly observable. Using speech, the intention of the robot can be conveyed in a direct way so that human users can directly evaluate it. Comparative user studies that expose subjects to various verbal behaviors of a robot are, therefore, an effective way to study user perception and preferences in HRI. Based on our own experience with system development and user studies [6] we attribute this “unpopularity” of comparative studies on robot verbal behavior to their methodological challenges:

Firstly, the content of verbal messages is relevant in such a study. The most important task of a dialog system is to communicate information about the robot's internal status to the user. Particularly in situations like robot technical failure the user can only rely on the dialog system to learn what has happened. The content of this information, especially the information about the current system status, is crucial in a user study on robot verbal behavior. However, in a WoZ study it is difficult to simulate all or many of the factors that affect the performance of the robot especially because many of these factors also have cross-correlations, e.g., the performance can be influenced by environmental conditions which in turn can also be affected by the user herself.

Secondly, the way when and how verbal messages are conveyed is also relevant. A dialog system directly communicates with users and they often infer the overall behavior of a robot from the behavior of the dialog system. For example, a robot that frequently takes task-related initiative may be perceived as more intelligent by users. This means, when and how the dialog system “says” something is an important factor in user studies on verbal behavior because they may shape robot's personality or its ability of social awareness. Using real robot systems to study such aspects requires a dialog system that can (1) demonstrate behaviors that reasonably affect user's impression in some way and (2) be able to demonstrate different behaviors to facilitate the comparative nature of such studies. However, most dialog systems implemented for robots today are based on *finite-state based approach*, e.g., [7], [8], [9], [10]. In this approach, the dialog system follows a script of prompts that are pre-defined for the domain tasks and the users need to answer these questions to make the dialog system to reach its goal state. Although it is still possible to use such systems to generate output of different verbal styles, it is difficult to vary “deeper” dialog aspects like initiative distribution that is not confined to individual utterances in certain context but

changes the whole interaction behavior of the robot. Thus, it is difficult to use these systems to study issues like when should the robot say something, which have great influence on the quality of *situated* communication like HRI.

Having looked at the special challenges of comparative studies on effects of robot verbal behavior we are convinced that we should combine the advantages of the two user study approaches for our robot. This means, *to develop a real dialog system with various verbal behaviors*. In user studies with such a system, different verbal behaviors can be directly contrasted to each other that are based on the identical, realistic, technical environment. Additionally to gaining insight related to verbal behavior, new research issues could also arise from this combination of the two user study methods (as discussed at the end of section III).

In this paper, we present such a dialog system for a mobile social robot BIRON (The Bielefeld Robot Companion) that can be easily configured to demonstrate different initiative taking behavior. After describing the dialog management mechanism in section II we forward to section III to discuss the results of a pilot study that provides strong evidence of the suitability of our system for conducting comparative user studies on robot verbal behavior. In this section we will also discuss the benefits we derive from this study. Finally, in section IV, we summarize the strength of our approach and outline potential use of this system.

II. THE DIALOG SYSTEM

In general, a dialog system is responsible for carrying out verbal interaction with users including transferring user commands to the robot control system and reporting task execution results to the user. During the conversation a dialog system should be able to regulate the initiative distribution, handle miscommunication, draw inferences between interlocutors' contributions and organize and maintain the discourse. To enable these abilities we implemented a powerful *agent-based* dialog model for our system. The basic idea of this approach is to view dialog as a collaboration between two equally intelligent agents both of whom take part in the conversation in the same way (see [11] for an overview).

A. The Dialog Management Mechanism

One of the most influential theories on the collaborative nature of dialog is the common ground theory of Clark [12]. In his opinion, during a conversation the interlocutors need to coordinate their mental states based on their mutual understanding about the current intentions, goals, and tasks. He terms this process as "grounding". Furthermore, a speaker can only be sure that her account, the so-called *presentation*, was fully understood if her interlocutor provides some evidence of understanding, the so-called *acceptance*, this is to say, if the "common ground" is available. Only then will the speaker be willing to proceed to another account.

We extended this grounding idea for robot applications: We represent interlocutors' contributions as *Interaction Units* (IU). Each IU has two layers: the intention layer and the conversation layer. On the intention layer a communication

intention is conceived which is usually based on the status messages from the underlying robot system. On the conversation layer a verbal or non-verbal output is generated based on the intention created on the intention layer. During a dialog, the IUs of the interlocutors mostly occur as pairs, e.g., one asks a question and the other answers it. We call these pairs of IUs *exchanges*. In each exchange, one IU plays the role of the presentation and the other the acceptance. Such an exchange is only grounded if the accepting IU is available. Sometimes new exchanges need to be created to ground the preceding exchange, e.g., if one says something that the other does not understand. In this case the listener probably initiates a new exchange to clarify what the speaker said. This means, there can be *grounding relations* between exchanges. We introduced 4 types of such relations (*Default*, *Support*, *Correct*, and *Delete*). These relations can have local effects on their preceding exchanges. For the reason of relevance we only discuss the relation *Default* and *Support* in more detail:

Default: The current Presentation introduces a new account that is independent of the previous exchange in terms of grounding. For example, if an agent says "Hello, my name is Tom, what is your name?" this utterance is segmented into three Presentations which initiate three *Default* exchanges. Such exchanges can be grounded independently of each other.

Support: If an agent can not provide Acceptance for the given Presentation she will initiate a new exchange to support the grounding process of the ungrounded exchange. Examples of such exchanges are Ex4, Ex5, and Ex6 in the dialog segment illustrated in Fig. 1. They are all initiated to support the grounding process of Ex3. If such a *Support* exchange is grounded its initiator will try to ground the preceding exchange again with the newly collected information through the supporting exchange. For our robot BIRON, we define, it may create acceptance IUs, i.e., to ground an exchange initiated by the user, only if (1) it understands the user utterance and (2) it successfully executes the task specified by the user. Otherwise BIRON has to initiate a *Support* exchange to let the user rephrase or say something else.

We organize these exchanges into a stack which represents the whole ungrounded discourse. If one interlocutor introduces an account into the discourse, one exchange is pushed onto the stack; if one exchange is grounded, then it is popped from the stack. According to different grounding relations actions can occur when an exchange is pushed or popped. Besides, the discourse is divided into discourse segments according to topics. Figure 2 illustrates the organization of the discourse. In short, we model the grounding process using an augmented push-down automaton which exhibits local flexibility in contrast to conventional grounding approaches ([13], [14]). Our system enables mixed-initiative dialog style and can handle complex conversational repair. (Our system is also able to handle multi-modal IUs, see [15] for more information. A detailed description of this dialog model can be found in [16].)

For the purpose of HRI user studies, the probably most outstanding feature of this system is that it is easy to make

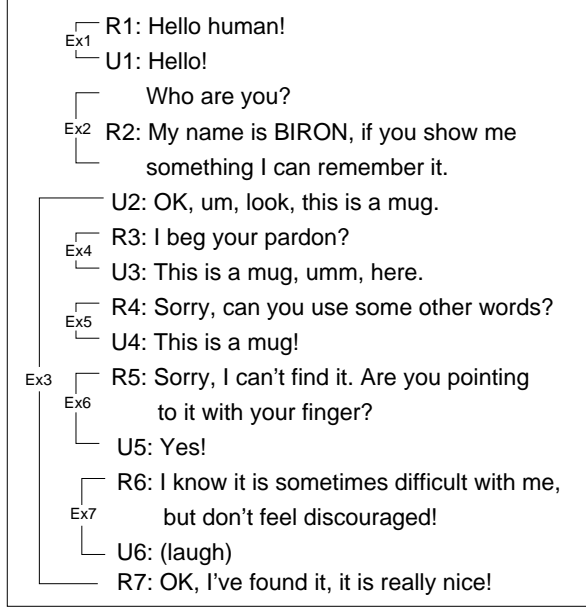


Fig. 1. Taking initiatives (Ex: exchange, U: user, R: robot)

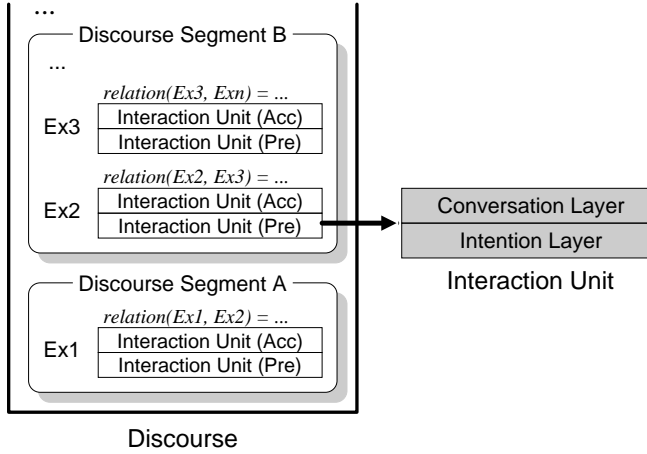


Fig. 2. The structure of the discourse (Ex: exchange; Pre: presentation; Acc: Acceptance)

the system “say something” and to handle user’s response to it from the discourse point of view. In the spirit of the agent-based dialog modeling approach, the domain tasks, in our case the status messages from the underlying robot system, are viewed as motivations for the system to create contributions that then participate in the dialog process according to general, *domain-independent* communication rules. This is the major distinguishing aspect of the agent-based approach against the finite-state based approach. To take initiative, the dialog system just needs to import the status messages from the underlying robot system and creates an IU for it. This IU then participates in the joint common ground building process as a part of an exchange that needs to be grounded by the user. The association of such robot status messages to the communicative intentions (that are to be created for the intention layer of a new IU) can be configured externally and, thus, be easily updated or replaced. This means, we can

easily control when the robot says something and what it says. In the following subsection we describe two behaviors that are realized based on this system capability and facilitate HRI user studies.

B. The Implemented Behaviors

Before describing the implemented behaviors we want to first depict the context in which they occur. Our dialog system is implemented on our robot BIRON, a personal robot with socially learning abilities. It can detect and follow persons, focus on objects (according to detected deictic gestures), and store collected multi-modal information into a memory. Our implementation scenario is the so-called *home tour*: a user bought a new robot from a shop and shows it her home to prepare it for future tasks. The robot should be able to learn and remember features of objects that the user mentions and it “sees”, e.g., name, color, images etc. This is also a learning scenario for the user because she interacts with a complex robot system for the first time. Within this context we implemented two initiative taking behaviors for BIRON that can be switched on and off. With the example dialog in Fig. 1, which is transcribed from a real interaction session between a user and BIRON, we describe these behaviors and our motivation in detail.

1) *Taking greeting initiative*: In the home tour scenario the user could have difficulty to start the interaction with BIRON at the beginning. After she unpacks and turns on BIRON she would feel a little bit helpless as to how to start the interaction. We think it can help to overcome this start difficulty if BIRON can greet the user on its own. This behavior would imply for the user that the robot now works, it has already perceived the user, and it can also speak human language. Probably the user would reply to this greeting intuitively as they do in human-human interaction. (This assumption is actually confirmed in our pilot study). The implementation of this initiative is quite simple: Once the robot control system detects a human in its vicinity it sends a message to the dialog system which then initiates a Default exchange (Ex1 in Fig. 1) to greet her (R1). Now the user is expected to provide acceptance that she heard and understood BIRON which is usually done by her reply to BIRON’s greeting (U1). In U1, the user also asks an additional question about the identity of BIRON. This question is classified as user’s initiative to create a Default Exchange that BIRON should ground by answering the question (R2). If the user had not answered BIRON’s greeting the dialog system would delete this self-initiated exchange from the discourse stack after a pre-defined time and, thus, delete the expectation that the user would reply.

2) *Making remarks on its own performance*: BIRON is a highly complex robot system including a large number of modules. Many of these modules carry out computationally expensive processing, e.g., face, gesture, and object recognition and speech recognition. The performance of many modules is also subject to environmental conditions, e.g., unexpected obstacles around can lead to failure of the follow behavior or the image processing can fail because of bad

lighting conditions. In a real user-BIRON interaction, this means, there is a variety of factors that can negatively influence the general performance of BIRON but users know nothing about. We think it can help to reduce user frustration if BIRON has the ability to show that it is also aware of its own problem and feels sorry about it. We, therefore, implemented the performance evaluation behavior for BIRON. The dialog system realizes this by counting the number of Support exchanges it has initiated for the current topic. Since the Support exchanges are only created if BIRON can not provide Acceptance to the user's Presentation (because it does not understand the user or it can not execute a task), the amount of the Support exchanges, therefore, has direct correlation to the robot's overall performance. On the other hand, the more Default exchanges there are, the better is the performance because the user and BIRON can proceed to another topic only if the current one is grounded (or deleted). Based on this performance indication BIRON makes remarks to motivate users. In our current implementation, BIRON makes remarks if it has had to initiate at least three Support exchanges for one topic or has grounded three Default exchanges in succession. In the dialog example in Fig. 1, BIRON could not understand the user's utterance twice (Ex4, Ex5) and then could not find the object specified by the user (Ex6) which resulted in the creation of three Support exchanges by the dialog system in total. According to this bad performance evaluation result the dialog system initiates the contribution R6 to motivate the user. If it were a positive evaluation result BIRON would say something like "You are really good at working with me." The wording style of these remarks is generated randomly from a set of 3 pre-defined sentences.

III. THE PILOT STUDY

In our pilot study we contrasted two verbal behavior types of BIRON in a between-subject design: *basic* and *extrovert*. The basic BIRON behaves rather passively and only says something if it is explicitly addressed by the user while the extrovert BIRON possesses *both* initiative taking abilities described above. Our goal of this pilot study was to find out if these two behavior types enabled by our dialog system can affect user impressions on our robot. If yes, this will be a strong evidence for the suitability of our system for comparative user studies on robot verbal behaviors. More specifically, the goal of this study was to test:

- 1) whether the different verbal behavior of the two types of BIRON are perceived as different;
- 2) whether the different perception of BIRON's verbal behaviors has effects on the perception of other features of BIRON such as its overall performance and interaction style;
- 3) whether the different perception of BIRON's verbal behaviors has effects on the subjects' emotional status.

A. Method

We recruited 14 subjects aged from 20 to 37 from the Bielefeld University. None of the subjects had interacted with

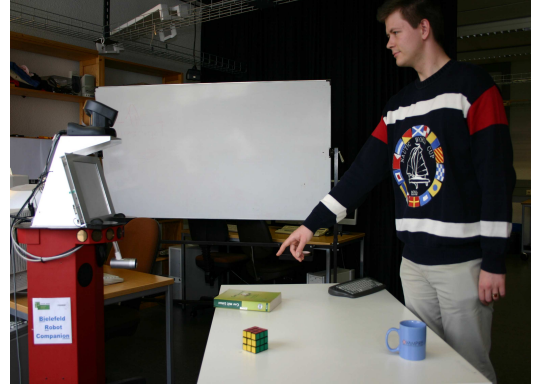


Fig. 3. The setup of the pilot study

BIRON before. In the pilot study, they were divided into two groups: 7 of them interacted with the basic BIRON (Group B) and the other 7 with the extrovert BIRON (Group E). They were just told to try out BIRON's functionalities without any knowledge about BIRON's technical limitations (Fig. 3). With this setting we intended to simulate the situation of the "innocent user" in the home tour and provoke technical failure to see users' reactions. In average, each subject interacted with BIRON more than 7 minutes. After the interaction the subjects were asked to fill out a questionnaire.

To answer the first goal question we asked subjects to rate BIRON's personality. As also assumed by [2], different behavior of a robot can cause subjects to perceive the robot as having different personality. We used 4 selected personality traits derived from the personality dimension *introversion vs. extroversion* that was proposed by Eysenck [17]. We think this dimension can be more easily associated with visible behavior and, thus, is more suitable for our purpose than his two other dimensions (*neuroticism vs. emotional stability* and *psychoticism*). The 4 traits are thoughtful vs. talkative, peaceful vs. responsive, quiet vs. active, and reserved vs. impulsive. The subjects rated BIRON's personality for each of the 4 traits using a 5-point Likert scale, e.g., 1 is very thoughtful and 5 is very talkative. For our pilot study, it is sufficient to assume that the higher value a selected item in the Likert scale has, the bigger is the tendency of the subject to classify BIRON's personality as extrovert.

To answer the second goal question we listed the four problems of our system that occur most frequently: BIRON loses the subject during the interaction, BIRON does not understand subject's utterances, the dialog with BIRON is restricted to a relatively small vocabulary and BIRON do not look in the direction of the subject's gesture. Subjects were asked to rate for each of these problems their degree of annoyance in a 5 point Likert scale. The associated questionnaire question was "How annoying were the following technical problems for you?". Additionally, we also asked users if they think the interaction style realized on BIRON is intuitive.

To measure users' emotional status after the interaction with BIRON for the last pilot study question we directly

asked them if they like BIRON.

B. Results

Given the small number of participating subjects we descriptively recorded the results of this pilot study. In the chart in Fig. 4 the result of the BIRON personality question is illustrated, the x-axis represents the personality tendency of BIRON rated by the subjects and the y-axis indicates the number of subjects who selected the corresponding items for the 4 traits. In Group B, subjects interacted with the basic BIRON and most of them thought BIRON tends to be introvert. For the Group E, the initiative taking behaviors of BIRON did lead to a clearly different picture than in Group B: extroversion is the most perceived personality tendency of BIRON even if the result is more distributed than in case of Group B.

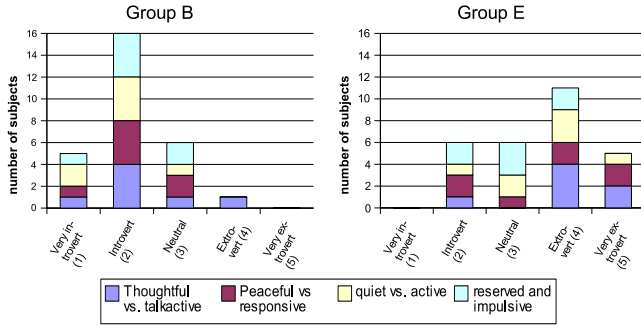


Fig. 4. The result of the question: "What do you think about the personality of BIRON?"

Figure 5 and Fig. 6 show the result of our second pilot study question. In the chart on their general annoyance degree, we can recognize a slight difference in subjects' general annoyance degree. We can even say that members of Group B seem to be generally more angry about the technical problems than those in Group E. On the issue of perceived interaction style, twice as many subjects in Group E approved the question as members of Group B.

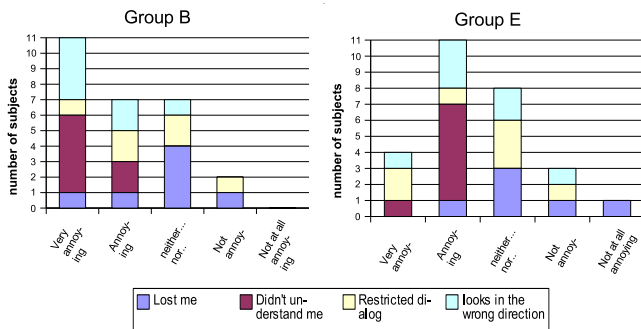


Fig. 5. The result of the question "How annoying were the following technical problems for you?"

The chart in Fig. 7 illustrates potential emotional effect of BIRON's different verbal behaviors. This result is a clear evidence for this effect: the overwhelming majority of Group

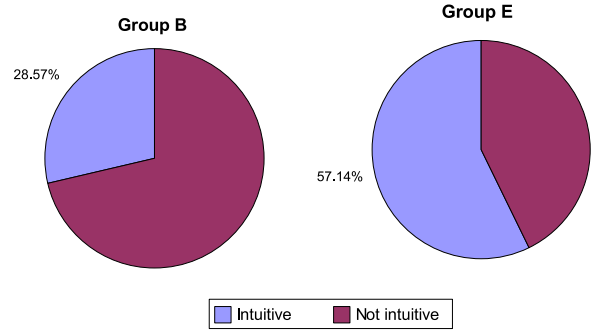


Fig. 6. The result of the question "Do you think the interaction with BIRON is intuitive?"

E liked BIRON while only a small minority of Group B held the same emotion.

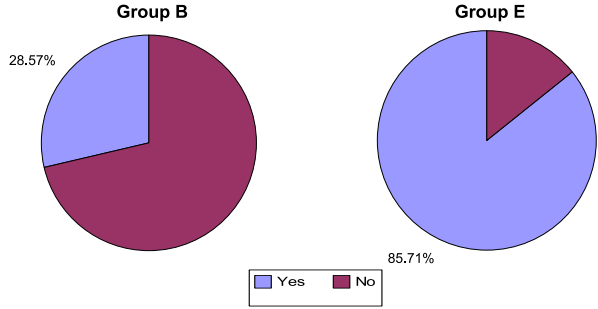


Fig. 7. The result of the question "Do you like BIRON?"

C. Discussion

The pilot study results suggest that the two verbal behavior types of BIRON were not only perceived as different, but the subjects' perception of the performance and the interaction style of BIRON were also affected, and the subjects of Group E (extrovert BIRON group) even felt emotionally animated in contrast to members of Group B. Although our study is a small-scaled pilot study, based on its clear results, we expect statistical significance of the relevant variables in larger-scaled user studies. Therefore, the pilot study results are strong evidence for the fact that our system is able to generate perceivably different verbal behaviors and is suitable for doing comparative user studies on effects of various robot verbal behaviors.

This pilot study also provides the first evidence for the benefits of a comparative user study on a real system as proposed in the section I. What we have learned includes the following two points:

- 1) *Human-awareness is important.* In the pilot study, the extrovert BIRON generally receives more positive comments from the subjects than the basic one. This result supports the advantage of human-awareness as proposed by [18] for robot motion planning domain. The extrovert BIRON demonstrates its awareness of human user's existence (by greeting her actively) and its awareness of possible emotional consequence on

users caused by its own poor performance. Such behavior does help to increase the acceptability of a robot.

- 2) *Human-awareness needs to be complemented by situation-awareness.* In our pilot study, we made the following observation: According to our experiment setup users were allowed to say anything they wanted to BIRON. But the speech understanding system of BIRON could only recognize a small number of words. Sometimes subjects were repeatedly misunderstood by the speech recognition system which caused the extrovert BIRON to initiate apology every 3 utterances. This behavior was in general rated as good by the subjects, but in this specific situation, the subjects were already annoyed by the speech recognition problem and, therefore, considered this kind of initiative as bothering. This example shows that a robot does not only need to be aware of human but also be aware of the situation and should make decisions taking into account observed situational cues.

To summarize the benefits of the comparative user study on a real system: if our pilot study had not been a comparative study, we might be able to assume the general benefits of human-awareness (as described in the first point), but we would not be able to quantify this difference to this extent which greatly helps to intensify our insight. Equally, if our pilot study had not been conducted on a real robot system with its inherent technical instability, we might not even be able to realize the complementary importance of situation awareness. Thus, our pilot study serves as a good example for the practical benefits of combining WoZ comparative studies with real robot testing.

IV. CONCLUSION

In this paper we presented a dialog system which can be easily configured to demonstrate various initiative taking behavior. In the pilot study conducted with this system the enabled verbal behaviors of our robot BIRON were clearly perceived as different and these differences also affect other factors of the user-BIRON interaction. Our system, thus, provides a suitable platform for doing comparative user studies on robot verbal behavior. Additionally, the combination of the advantages of comparative WoZ study with real robot testing also turned out to be productive in terms of gaining general insights in HRI.

To be used in comparative user studies on robot verbal behavior in general, our system is not confined to the implemented behaviors as described in this paper. It will be quite simple to enable BIRON to take initiative of other types, e.g., a task planner can provide task specific information to the dialog system so that the robot can take task-related initiative, this means, it can potentially make constructive suggestions when doing tasks collaboratively with the user. Besides, initiative behavior can generally be parameterized to adapt to the robot's knowledge of the current social situation, e.g., the dialog system can be configured in a way that it only takes greeting initiative when the robot's vision system can recognize user's willingness to interact with the robot. Since

the initiative taking behavior can be easily modified in our system, we can, as well, contrast verbal behaviors based on the principles above in comparative user studies.

V. ACKNOWLEDGMENTS

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