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Development of HRI Models by means of a Cognitive Walkthrough Approach

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Abstract. Well established interaction models are the source of successful human-robot interaction user studies. We propose a methodological adaption of the Human-Computer Interaction expert evaluation method cognitive walkthrough as approach to develop interaction models based on video data from previous user studies. To investigate this methodological adaption we conducted a cognitive walkthrough taking advantage of videos of two user studies with two different humanoid robots. Based on the implications gained from the cognitive walkthrough, a set of implications for a general interaction model was developed which served as basis for new interaction scenarios with reduced usability problems.

1 INTRODUCTION

Two key elements for successful human-robot interaction are interaction *models*, representing procedures and characteristics of the interaction in a general way and interaction *scenarios*, representing scripts of the story behind the interaction. Scenarios are also a proven method in the area of HCI/HRI to describe concrete situations of human-robot interaction [8], involving personas and specific tasks, whereas interaction models are more general, focusing on the input-output stream of an interaction. The development of interaction models helps to increase usability aspects like intuitiveness and learnability on a basic level and assures these aspects for all interaction scenarios derived from it. Thus, interaction models build the basis for a broad range of interaction scenarios with a minimal number of usability problems.

But how to generate such general human-robot interaction models? In this position paper, we propose an adaption of the classical cognitive walkthrough method from Human-Computer Interaction to identify the critical areas of human-robot interaction scenarios and to derive implications for more general human-robot interaction models rooted in the respective context of use. In other words this paper aims to present a method for structuring scenarios in action sequences. By describing a concrete application of our adapted cognitive walkthrough in two case studies, the reader is introduced to the stepwise translation process of HRI scenarios to HRI models. Our adaption is mainly characterized by the usage of concrete interaction scenarios represented in video-taped, task-based human-robot interaction user studies. These scenarios are then presented to a group of experts who walk through the interactions and identify the major usability problems regarding intuitiveness and flexibility. Based on the combination of a user-centered hierarchical task analysis of the examined scenario and the identified usability problems, a general interaction model can be proposed.

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The paper is organized in the following way: First, we give an overview on the related work concerning the cognitive walkhrough method and scenario-based approaches in HRI, as well as high level interaction models for human-robot interaction. Next, we describe the methodological set-up of our cognitive walkthrough adaption for getting more general interaction models of a human-robot interaction out of concrete scenarios. By presenting two case studies we then illustrate the concrete usage of our method. Finally, we discuss the scope and limitations of the presented methodological adaption and show possible future use cases of it.

2 RELATED WORK

Our approach is characterized by an indirect assessment of human-robot interaction, i.e. the observation of the interaction scenarios presented on video. In general, user interaction scenarios help to make a system's use explicit [9]. According to Rosson and Carroll, user interaction scenarios represent an effective design tool for inspiring and systematizing the iterative development of interactive systems.

Videos can be used as instantiations of scenarios in order to represent prototypes, thus helping to bridge the gap between abstraction and detail in the design process [4], [5]. Up to now, video-based methods are not very common in HRI. However, video trials could represent an alternative to live trials, as running a live human-robot interaction trial under controlled conditions with statistically valid results requires a relatively high investment of time, resources, and personnel [15].

A fundamental question when using video based methods in HRI is if people's perceptions from live and video trials are comparable. This question is discussed by Woods et al. [15]. In a pilot study, they could show that videotaped trials are a valuable technique for investigating people's perception of presented human-robot interaction scenarios, as the participants' preferences and opinions were similar in both trials (video-based and live). The authors indicate that video trials should not be seen as a replacement for live trials but rather as a complementing research tool.

In a study of Kidd [3], it could be shown that there are no fundamental differences between present and remote interaction with a robot head (via video) when rating personality traits.

A study of Sydral et al. [11] focused in particular on how participants evaluated three robotic systems in terms of user experience, after having presented a brief video showing how a human interacts with a robot. The authors found out that video-prototyping represents a valuable instrument for evaluating how prototypical systems are experienced by users.

In a study of Buur et al.[1], videos were used to discuss different types of mobile interfaces. Therefore, the participants had to select three problematic situations, which in their view would be good test cases. After that, each group prepared a short video scenario which was later shown to the other participants and then discussed.

The studies presented above let us assume that videos are a promising instrument for investigating human-robot interactions under certain conditions (i.e. at an early stage of development).

In order to describe the way a system acts, interaction models can be used. Such models act as a base for successful design of systems including high usability. Interaction involves at least two participants, the user and the system; interaction models are helpful for understanding exactly what is going on in the interaction and for identifying the likely root of difficulties. In general, interaction models are used for planning, describing, and analyzing systems/interactions with systems. What is more, a model gives the possibility to compare different applications/systems/prototypes and provides a unified language. By applying interaction models, possible procedures and interactions can be simulated and possible problems can be identified [2].

In the area of HRI, interaction models do not have a long tradition and thus only exist sparsely and incompletely. One of the best known interaction models in HRI is that of Scholtz [10], which is based on Norman's seven stages model [6]. Scholtz assumes that HRIs are of five varieties, each needing different information and being used by different types of users. Therefore, five roles are defined: supervisor, operator, mechanic, bystander, and teammate role. Supervisory and teammate roles imply the same relationships between humans and robots as they do when applied to human-human interactions. An operator is needed to work "inside" the robot; this includes adjusting various parameters in the robot's control mechanism to modify abnormal behavior, changing a given behavior to a more appropriate one or taking over and tele-operate the robot. The mechanic role is adopted when a human needs to adjust physical components of the robot, such as adjusting the camera or various mechanisms. A bystander does not explicitly interact with a robot but needs some model of robot behavior to understand the consequences of the robot's actions. Based on these roles, possible models of interaction for the various HRI roles are presented, namely supervisor interaction, operator interaction, mechanic interaction, peer interaction and bystander interaction.

3 METHODOLOGICAL SET-UP

3.1 Video-based cognitive walkthrough

3.1.1 The Cognitive Walkthrough as a Usability Inspection Method

The cognitive walkthrough is a usability inspection method to evaluate the design of a user interface [7]. It puts special emphasis on the ease of learning, primarily by exploring the application without a prior instruction or training. The method is based on observations showing that users prefer to learn a software by exploring it. To evaluate a proposed interface, experts are asked to walk through action sequences of a specific task and assess the cognitive effort required by the user when interacting with the interface in the optimal course of action. The method aims at finding "mismatches between users' and designers' conceptualization of a task" [14].

The cognitive walkthrough used within usability inspection in the field of HCI consists of two phases. In a first preparatory phase the context for the use of the system is defined. This includes concrete information on the target group, the system and the tasks that are to be performed. The second phase consists of the actual walkthrough and the locating of potential usability problems. The central question within this second phase is whether the user would behave the way it is required by the interface to successfully solve the given task.

3.1.2 Adaption of the Cognitive Walkthrough for HRI

In order to use the cognitive walkthrough for the purpose of examining human-robot interaction scenarios, we slightly adapted the cognitive walkthrough method. However, the main aim of the adapted cognitive walkthrough still was to increase usability aspects like intuitiveness and learnability - which we believe essential for human-robot interaction, especially when designed for unexperienced users - and integrate these into the scenarios. For the first phase - the analysis of the context of use - we resorted to information and scenarios that had already been deployed in the two user studies (see 3.2). According to the scenario, the participant would have the role of a teammate as defined by Scholtz [10]. The scenarios further described the target user and the tasks to be analyzed. These scenarios were already tested in user studies and videotaped at this occasion. In classic cognitive walkthrough the interface or a description of the interface is given in detail at each action sequence. If the interface is not fully developed paper descriptions of the interface can be used. As human-robot interaction is not limited to a graphical user interface, we opted to use video material to present each action sequence to the group of experts. We wanted to give the experts a more complete picture of the interaction instead of only handing out a list of all possible commands and feedback given from the robot. The video-based material of the user studies served as basic input for expert evaluators. We assumed that the video material could help the evaluators to better relate to the potential user. We selected video clips of participants who solved the task without any errors in order not to bias the evaluators. These clips were cut into single action sequences for an easy handling during the cognitive walkthrough sessions.

3.2 The user studies

Two user studies preceding the cognitive walkthrough served as preliminary studies to evaluate the usability of the initial interaction sequence represented in the scenarios. They further had the goal of investigating how novice users experience the collaboration with the humanoid robot. The first of the two user studies was conducted at LAAS Institute of CNRS in Toulouse, France.

Figure 1. Study Setting: HRP-2

The participants had to accomplish two tasks which were based on speech recognition and on interaction with the HRP-2 robot - see Figure 1. Their performance and behavior was observed, recorded on video tape and analyzed at a later date. In task 1, the participants' job was to tell the robot to pick up the ball; in task 2, the participant's job was to tell the robot to put the ball on the table. The participants were introduced into the scenario. They received a list of commands needed in order to fullfil the task as well as some additional commands to interact with the robot. An interaction model itself was not developed. In order to fully understand the task we conducted a hierarchical user-centered task analysis of the interaction scenario, see Figure 2. More details on this user study can be found in [12].

The second user study took place at the LASA Institute of EPFL in Lausanne, Switzerland. In order to find out more about human-robot interaction with the HOAP-3 humanoid robot, the participants had to accomplish two tasks based on learning by demonstration. The tasks were video-taped an accompanied by a retrospective think aloud. The two tasks - both based on demonstration of specific motions - had to be conducted: In task 1, the participants had to teach the robot to push a box away from its working space into the users' direction; in task 2, the participants' job was to teach the robot to close the lid of a box.

Figure 4. Study Setting: HOAP-3

Before starting with the task, the scenario was described by the instructor: "Imagine you are working at an assembly line in a big fabrication plant. A new robot is introduced, which should support you in solving tasks. You can teach the robot specific motions by demonstrating them (meaning move the robot's arm like you expect it to move it later on its own); the robot will repeat the learned motion. You can repeat this "demonstration-repetition-cycle" as long until you are pleased with the result". The interaction model for the scenario can be seen in Figure 5. Based on the scenario and the interaction model we conducted a hierarchical user-centered task analysis of the interaction scenario as already done with the HRP-2 interaction. Figure 3 represents the hierarchical user-centered task analysis of the interaction scenario. More details on this user study can be found in [13].

Figure 5. Study Setting: HOAP-3

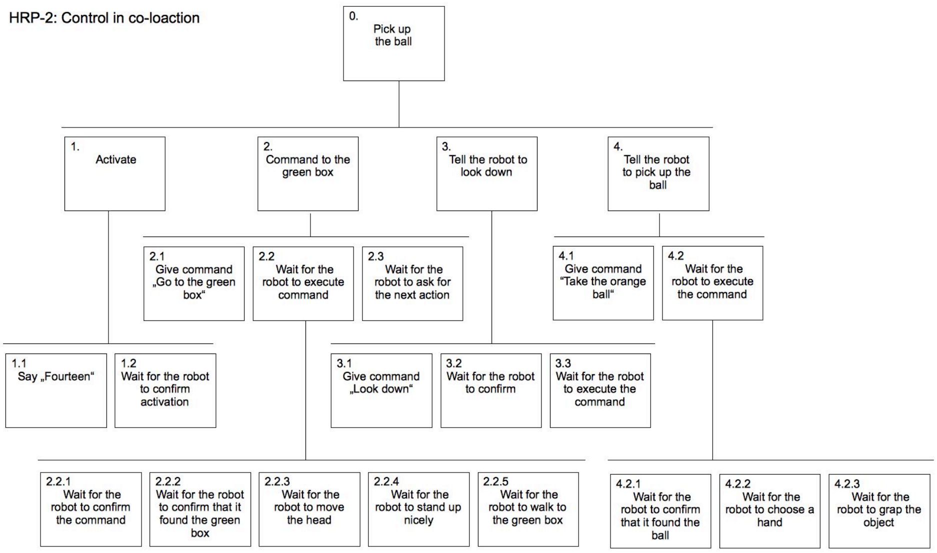

Figure 2. Task Analysis: HRP-2

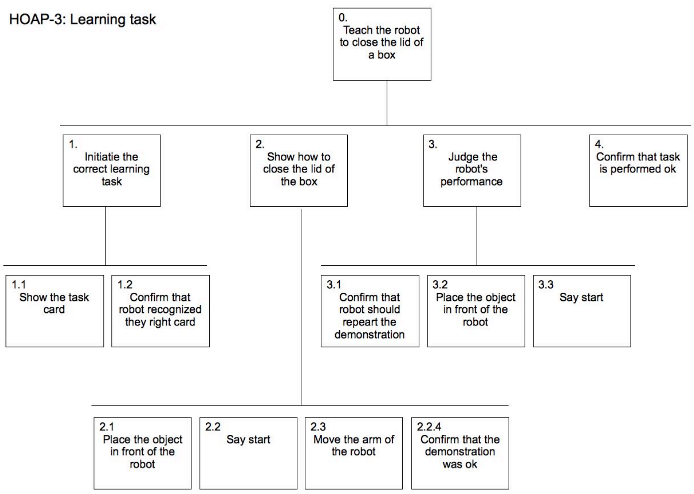

Figure 3. Task Analysis: HOAP-3

3.3 Evaluation setting and procedure

For each task of the user studies a separate cognitive walkthrough was conducted. A group of four experts from the field of Human-Robot Interaction participated in the walkthroughs that were organized and moderated by a researcher. Each session lasted about two hours. An assistant took notes during the whole procedure.

At the beginning of each session, the moderator introduced the experts to the scenario. Each participant received a scenario card (see Figure 6) with a detailed description of the scenario as well as of the two tasks which had to be analyzed by the expert group. For the actual walkthrough, each task was divided into action sequences, the video clips taken from the user studies were prepared accordingly. The evaluators went through each step of the action sequence by watching the video clip first and discussing if and why a user would choose the correct action at each step afterwards. Special attention was paid to whether the robot's feedback was sufficient. After the sessions were completed, the transcript of the sessions was analyzed by two researchers and the results, summarizing cognitive effort and possible problems of each step within the task, were collected.

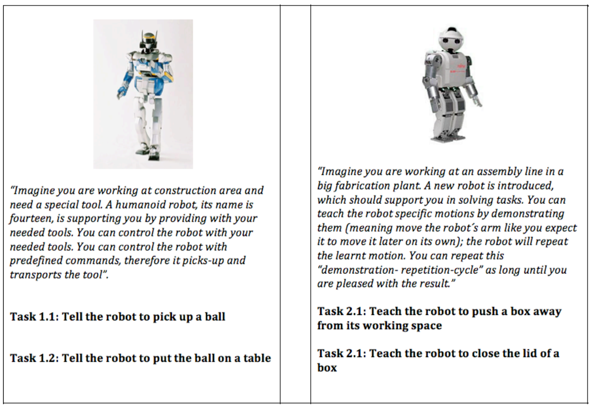

Figure 6. Scenario Card

3.4 Cognitive walkthrough results

Based on the results of the cognitive walkthrough (see problem list of Table 1), we developed a set of implications for general interaction models supporting a high level of learnability and intuitiveness. As theoretical base, we took the definition of learnability from Dix et al. [2]. According to the authors, learnability deals with the characteristics of an interactive system that allows novice users to understand how to use it initially and attain a maximal level of performance. For describing learnability in detail, Dix et al. define five principles which affect learnability. These principles are predictability, synthesizability, familiarity, generalizability and consistency. The results of the cognitive walkthrough and the implications for improving certain aspects/principles of learnability for general interaction models are listed below.

Results concerning synthesizability and consistency Giving feedback is related to the principle of synthesizability, enhancing learnability in a positive way. Synthesizability should support the user to assess the effect of past operations on the current state. Consistency is a further principle affecting learnability, dealing with the likeness of input-output behavior arising from similar situations or similar task objectives.

Table 1. Overview Cognitive Walkthrough Results

Problem	HRP-2	HOAP-3	Resulting Implications
No information on status of the robot	X		Imp 1
One-dimensional feedback (not multimodal)	X	X	Imp 2
Not feedback from the robot at all	X	X	Imp 1, Imp 3
No predictability of robot action	X		Imp4
No information on the vision field of robot	X		Imp 4
Low flexibility	X	X	Imp 5
No options of stopping or canceling an action	X	X	Imp 6
No possibility to start interaction/an action	X		Imp 6
Unclear output from the robot		X	Imp 7

Imp 1: Provide visual feedback about status of the robot: It is essential for the user to know the robot's status at every point of interaction. Therefore, cues for understanding whether the robot is activated / is in a mode of receiving commands / executing any commands have to be provided. Visual feedback via lights (on the head, shoulders, in the eyes), body language, gaze direction, gestures and posture could be used for indicating the status of the robot. For example, an inactive robot looks down, whereas an activated robot looks into the user's direction. The advantage of visual feedback is that it is understood easily and intuitively by the users.

Imp 2: Provide multimodal feedback: One feedback modality is often not sufficient for getting clear and unambiguous feedback. More information about the robot's current status could be provided for example by accompanying movements or gestures. For more details concerning this issue, see below Imp 2a.

Imp 2a: Support auditory feedback by other feedback modalities: The understanding of auditory feedback must not be crucial. Especially when a robot uses auditory feedback, this can pose problems. For example, if the noise level of the environment is high, the verbal output of the robot can be difficult to understand. Therefore, other feedback modalities should enhance the auditory feedback.

Imp 3: Provide consistent feedback: The robot's behavior should be consistent and unambiguous (e.g. eyes have to be illuminated every time the robot is active). Furthermore, in case of multimodal feedback, consistency of the different output channels /feedback modalities has to be ensured. Moreover, response times of the robotic system must not be too long, otherwise the user cannot correlate his actions with the system's reactions. Unnecessary feedback/information should be avoided as it distracts the user. Giving immediate and relevant feedback thus supports learnability. In order to provide coherence, feedback should not only be given in case of success (of an action), but also in case of failure.

Results concerning predictability Predictability is a principle which affects learnability. It means that the user should be supported determining the effect of future action based on past interaction history.

Imp 4: Inform about the robot's perspective: For a human interacting with a robot, it is not always clear how the vision of a robot works and which objects can be seen or recognized by the robot. For example, objects that are too close to the robot might not be detected. Information about the robot's perspective/vision range could be given by an ambient display, giving information about the robots field of vision. This helps the user in learning to evaluate the robots vision field correctly and in turn supports efficient interaction with it.

Results concerning familiarity Familiarity is a principle of learnability, saying that the extent to which a user's knowledge and experience in other real-world or computer-based domains can be applied when interacting with a new system.

Imp 5: Allow flexibility in interaction: A robot should be flexible concerning the sequence of actions, the input modalities and the length of the feedback. Flexibility in the sequence of actions means that some steps of one sequence can be skipped if they are not necessary in the interaction. The input modalities for controlling a robot should also be kept as flexible as possible, meaning that the user can select one of several different input modalities. For example, when collaborating with a robot in a factory, switching between controlling the robot with verbal input or a remote control can be beneficial depending on the situation. Generally, verbal input is faster and does not require any devices (both hands are free). However, if there is a lot of ambient noise, controlling the robot via remote control can be more efficient. The length of the feedback given by the robot should be reduced to a minimum. Only feedback which is informative for the user should be given. Needless information / feedback should be avoided, as it is distracting and time-consuming for the user. The possibility to skip certain steps should be provided in order to shorten interaction times for more advanced users. When interacting with a new system, novice users often rely on the principle of trial and error. In case of error, the system has to react accordingly and give feedback about the error. In order to enable trial and error, it is necessary to let the user control the situation (and not the robot). Flexibility accounts to the principle of familiarity in so far, as the user can adapt the system's behavior so that it becomes familiar for him/her.

Imp 6: Provide distinct possibilities for controlling the robot: Stopping the robot, cancelling a current task / action of the robot as well as putting the robot in stand-by state should be always provided. These actions are familiar for the user and are therefore easy to understand and learn. It is important to provide the possibility to stop or cancel wrong actions. The difference between stand-by and activation must be clear and unambiguous. Automatic stand-by after certain time is especially important due to safety reasons.

Results concerning generalizibility Generalizibility is a principle of learnability, saying that there should be support for the user to extend knowledge of specific interaction within and across applications to other similar situations.

Imp 7: Support easy commands: In order to support the principle of generalizibility and in turn enhance learnability, commands have to be short, easy to remember, unambiguous and consistent. Therefore it is essential to use verbal cues and commands which are familiar and common for humans. For example, activating a robot by saying its name is intuitive for the human user, as this is also a common practice in human-human interaction. When controlling the robot verbally, possible interferences have to be taken into account. For example, efficient control of the robot is strongly dependent on the robot's position in relation to the users' position.

4 General interaction model

Based on the results and implications regarding usability (with a special focus on learnability) the expert evaluators developed a general interaction model for "speech-based human-robot interaction" and "learning by demonstration interaction". These general interaction models focused on the human input, the robot output, and the procedure on a very general level. Based on the general interaction model the interaction scenarios of the two case studies were re-desinged and are presented in the following.

4.1 Re-designed HRP-2 interaction scenario

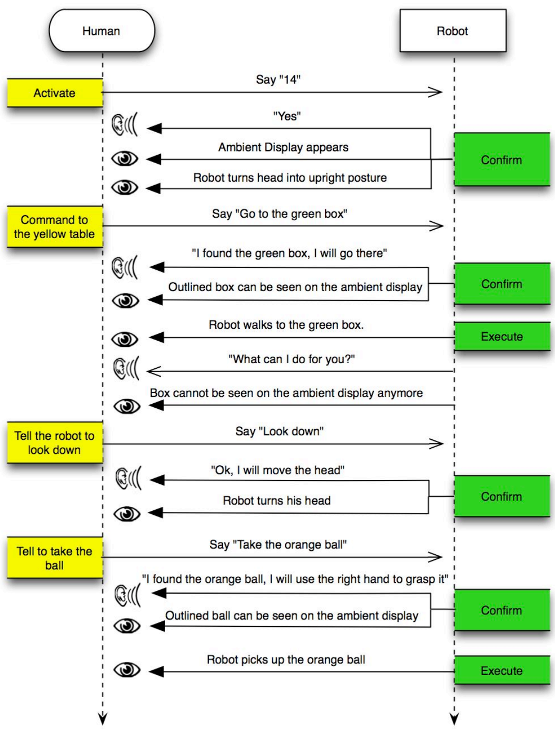

Figure 7. Interaction Model: HRP-2

Figure 7 shows the re-designed HRP-2 scenario. The tasks of the human are on the left side, the arrows towards the right represent the commands of the human. On the right hand side the output (confirmation) and the actual reaction of the robot (execute) can be seen. The re-designed scenario indicates how major problems detected in the human-robot interaction can be solved: feedback and output modalities. In the interaction scenario of the preliminary field study the feedback was limited to audio output (voice) and the actual action (physical movement) of the robot.

Multimodal feedback is therefore advisable. The re-designed interaction scenario suggests a set of additional feedback modalities. As can be seen in the first confirmation of the robot in the diagram the body movement of the robot can be used as feedback on its status, easily allowing status detection. E.g. an inactive robot has its body crouched down. An additional possibility (not included in the sequence diagram) for giving feedback on the robot's status and its actions could be a light on the robot (eg. On the head or on the shoulders) that indicates the status of the robot. Four different statuses are suggested: (1) Stand-by, (2) ready for input/commands, (3) processing a command, and (4) executing the command.

Another way that is presented in the model diagram for enriching the feedback is by providing an ambient display. Through the display the vision field of the robot could be made traceable and thus comprehensible for the user. Its importance can for example be seen in the step where the participant needs to command the robot to look down. As he/she has just commanded the robot to the green box, it is illogical that the robot cannot detect the green box anymore, once being there. The ambient display giving information on the robot's field of vision helps to solve this issue. It shows the user that the robot cannot detect the green box at this point but the head needs to be turned downwards first. The ambient display can also show next actions or movements taken by the robot. This can increase predictability of the robot's action. In the re-designed model some of the robots auditory outputs were modified and reduced as the cognitive walkthrough revealed that not all information is necessary and reducing the amount of information output of the robot can ease learnability . Apart from feedback modalities, it is important to give the user the feeling of control. Hence, the options of stopping or canceling an ongoing action are crucial. As the sequence diagram portrays an ideal course of action this command is not included. However, they should be considered in the re-designed model.

4.2 Re-designed HOAP-3 interaction scenario

Figure 8 presents the re-desinged HOAP-3 interaction scenario.As feedback modalities showed to be of highest importance during the cognitive walkthrough of the HOAP-3 scenario, the first step in redesigning the scenario was to rework the feedback model. The issues of consistent feedback upon all feedback channels (including body language, illuminated eyes, speech output, and actions) and multimodal feedback were considered. First, it is important to stress that gestures, gaze direction, and speech output of the robot need to be consistent, e.g. the moment the person puts a box on the table the robot should turn its head towards it indicating that it detected the object. The speech output of HOAP-3 was reduced and clarified in the re-designed interaction model according to the suggestions of the experts that took part in the cognitive walk through. To help a novice user to successfully interact with the robot, feedback on the user's actions would be of help: Is the box put onto the correct position or in which ways can the robot's arm be moved (by demonstrating the different degrees of freedom). Such additional help should at the same time be easily skippable.

Apart from the feedback the re-designed interaction model offers

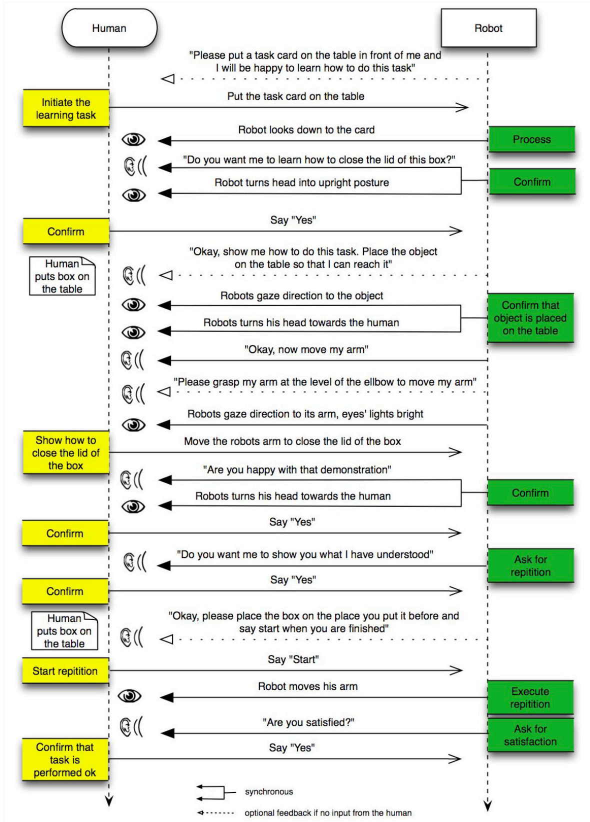

Figure 8. Interaction Model: HOAP-3

more flexibility to the user. First of all it is important that the user is given the possibility to start the interaction. That will avoid causing the feeling of the robot being in control of the situation. In the sequence diagram of the re-designed interaction model this is indicated by dotted lines. Only in case that no input/command is given by the user the robot will ask for a task card or give some information on what it requires the user to do. Giving the use the possibility to stop or cancel an ongoing action could even further increase flexibility. Therefore additional speech commands would be necessary which were not taken into account for the presented general interaction model.

5 Discussion and Outlook

This position paper reported about a methodological adaption of the cognitive walkthrough approach to allow the abstraction from specific HRI scenarios to more general HRI models in a specific application domain. Our main assumption was that the general models can serve as main narrative for other HRI interaction scenarios in order to reduce potential usability problems and increase intuitiveness and flexibility of the interaction. Two case studies were presented which described how a video-based cognitive walkthourgh can be used to develop such general interaction models.

Generally speaking, the use videos of concrete human-robot interaction scenarios as input for expert evaluations to develop general interaction models seems to be a reasonable approach. As numerous severe usability issues could be identified by means of the adapted cognitive walkthrough and diluted in the subsequently developed interaction models, we consider the approach as effective. Thus, we suggest that applying this methodological adaption can be valuable for (1) improving human-robot interaction scenarios (e.g. for iterating the set-up of a user study before all participants are tested) and (2) developing general human-robot interaction scenarios as narratives to derive variations of interaction scenarios.

However, to verify our proposed method, comparative proof-of concept user studies will be necessary to investigate if the scenarios based on the two presented interaction models actually offer less usability problems in the areas of intuitiveness and flexibility once in the field. For the future we plan to use the presented interaction models as source for the development of different, specific interaction scenarios to validate our proposed methodological approach. Moreover, it is desirable to apply the proposed cognitive walkthrough approach at an earlier stage of the development phase. Instead of video material of a first user study an animation video of the foreseen scenario could be used for the expert evaluation. Additionally, we want to gain insights on the question whether a user-based cognitive walkthrough even produces more robust interaction models compared to expert evaluations.

We conclude that our methodological adaption of the cognitive walkthrough represents a first step towards a beneficial approach to detect potential usability problems in human-robot interaction scenarios, especially at an early stage in the development phase, and thus is a valuable complement for human-robot interaction research. Even so, further research to proof evidence of the feasibility of this approach in terms of developing general interaction models will be indispensable.

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