ROBEE: A homeostatic-based social behavior controller for robots in Human-Robot Interaction experiments

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***Abstract*— This paper presents the development and implementation of ROBEE, a novel social behavior controller for robots with a focus on Human-Robot Interaction (HRI) studies. Using the homeostatic drive theory, ROBEE selects the behaviors in order to maintain the needs, mainly psychological and social, within an acceptable range. We propose a hybrid concept for the decision making process, which combines the hierarchical approach and Parallel-rooted, Ordered, Slip-stack Hierarchical (POSH) architecture. Emotions are mapped in a two-dimensional space consisting of valence and arousal. A joint attention HRI experiment with children and NAO robot has been conducted showing the usage of the controller. ROBEE is expected to be implemented in more robotic platforms.**

I. INTRODUCTION

Human-Robot Interaction (HRI) is an emerging field aimed at improving the interaction between human beings and robots in various activities. Being different from human-computer interaction and human-machine interaction, HRI concerns complex dynamic control systems operating in real-world changing environments which require more autonomy and cognition [1]. During the last decade, a number of social robot platforms have been developed with the ability to exhibit social behaviors, and capability to work with non-expert users at home, school, clinic, hospital, museum, etc [2]. Unlike the traditional robots operated by experts and work as tools in industry, social robots are expected to behave in more natural manners. For example, robots in museums must be able to detect and recognize the actions and intentions of a person, and to produce appropriate reactions [3]. Robots in robot-assisted therapy are required to have more substantial levels of autonomy which would allow the robot to adapt to the individual needs of children over longer periods of time [4]. However, most of robots are still operated with pre-programmed scenarios or under remote-controlled mode, which are deployed in a technique called Wizard of Oz (WoZ). Therefore, it is necessary to have solutions to enable social robots to make decisions and express emotions more autonomously.

Researchers in cognitive robotics have developed and implemented a number of architectures for artificial agents including robots and computer software. The architectures, on one hand, are inspired from neurobiology by using Artificial Neural Network (ANN) techniques, e.g, Bottom-Up Mechanism for Behavior Selection [5], integrated Behavior-Based Control (iB2C) [6]. On the other hand, a lot of architectures follow the psychological point of view, which uses multiple layers to model involuntary and voluntary behaviors. These architectures are mainly based on the homeostatic drive theory, in which behaviors are executed to maintain the agent's internal needs within a certain range [7]. However, the decision making systems are organized in different ways e.g. AIBO [8] and Kismet [9] use a hierarchical and top-down approach to select behaviors, while Bryson introduced the concept of "Behavior Oriented Design" to select behaviors opportunistically depending on their priorities and preconditions with the Parallel-rooted, Ordered, Slip-stack Hierarchical (POSH) reactive plans [10].

Emotions also play an important role to make the human-robot interaction more natural [9][11]. Different theories of modeling emotions are based on basic emotions, continuous scales, or both [12]. Robots with emotions can be listed as AIBO [8], Kismet [9], Probo [13], etc.

The work presented in this paper is the development of ROBEE, a novel RObotic social BEhavior controller for robots in HRI Experiments, based on the psychological point of view using homeostatic drive theory. Focusing on HRI studies, the internal needs are extended to psychological and social necessities. Behaviors are organized in two layers: reactive layer for involuntary behavior and deliberative layer for voluntary behavior. Behavior selection mechanism is designed by combining the modularity of the hierarchical approach and the opportunism of POSH. This combination is advantageous since it is easily understandable for non-experts and allows the robot to skip unnecessary steps. Emotions are modeled using a two-dimensional space consisting of valence and arousal, based on the circumplex model of affect defined by Russell [14]. ROBEE is implemented in NAO, a 25 degree-of-freedom robot developed by Aldebaran and widely used in HRI studies [15]. A user-friendly graphical interface provides the operators an ability to program high-level behaviors. A joint attention experiment with children has been conducted showing the usage of ROBEE.

This paper is organized as follows. Section II reviews the basic concepts related to animal and human behaviors and inspired architectures in neurobiological and psychological point of views. In section III, we present the architecture of the social behavior controller ROBEE. Section IV shows how our controller is implemented in NAO robot. The joint attention experiment using ROBEE is described in section V. Finally, conclusion and future work are provided.

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II. Related work

Oxford Dictionaries defines the word "behavior" as the way in which an animal or person behaves in response to a particular situation or stimulus. Behavior can be looked at two different angles: *neurobiology* and *psychology*. In this section, we give a brief review of the basic concepts and architectures related to both point of views.

A. Neurobiological point of view

In animal or human nervous system, behaviors are generated by a giant interlinked network of neurons: sensory neurons-sensor input, interneurons-integration, and motor neurons-motor output. According to [16], property of a behavior is determined by the way information is processed. On one hand, a behavior is innate and involuntary, which is referred to as *reflex* e.g. knee-jerk reflex, if the processing is done in the spinal cord where sensory neurons are directly connected to motor neurons. Reflexes protect the agent body by rapidly responding to particular stimuli. On the other hand, *voluntary behaviors* are controlled by the cerebral cortex where sensory inputs are processed to select a specific behavior, which is then transmitted to motor outputs.

The neurobiological principle has inspired scientists to model behavior of artificial agents using ANN techniques. However, most of the ANNs implemented in robot platforms are used to perform navigation tasks. As for social robot behavior, Maes proposed and tested the "Bottom-Up Mechanism for Behavior Selection" neural-network-based architecture for motivational competition and selection of behavior [5]. Hirth developed and implemented the integrated Behavior-Based Control architecture (iB2C) in which behaviors are adapted to the variation of motivation [6]. The main difficulty that limits the use of ANNs in modeling behavior is the requirement of sufficient learning time to create database, which is not always appropriate for HRI studies.

B. Psychological point of view

In behavioral psychology and artificial intelligence, it is widely accepted that behavior is organized in three layers, even though the nomenclature of each layer might be different. In this paper, we use the terms *reactive*, *deliberative*, and *reflective* layer to reconcile the theories of different authors such as Orthony *et al.* [17][18] and Sloman *et al.* [19][20].

- *Reactive* layer is constituted by the lowest-level-processes which are generally determined and not evolved due to learning. State information, coming from sensory inputs, is immediately acted upon with appropriate motor outputs. Behaviors related to this layer are similar to reflexes in the neurological point of view.
- *Deliberative* layer corresponds to complex and skilled behaviors, and guides most of motor actions. At this layer, the agent conceives a plan taking inputs from the sensory, reactive layer, and reflective layer. This plan is then executed in order to fulfill a certain goal. In addition, much of the content at this level is learned.
- *Reflective* layer is the most complex form of the conscience in which the mind deliberates itself. Unlike the lower layers, reflective layer is not linked with sensory and motor systems. This layer evaluates the plans (formed by the deliberative layer) and may decide to change these plans in order to better attain the goal. Therefore, it functions is "to think", not "to act".

Decision making system helps an agent to solve two main issues in selecting behavior i.e. "what to do" and "when to do". Dominating among different approaches is the *homeostatic drive* theory [7]. *Homeostasis*, first introduced by Cannon in [21], means maintaining a stable internal state. In other words, an agent has a number of internal needs (e.g., hunger, thirst, and nutrient appetites) which have to be kept within certain ranges. The internal needs can be extended to psychological and social necessities [22]. When one or several needs are not satiated, it creates a motivational state, called *drive* by Hull in [23], to trigger appropriate correction actions.

One of the main differences among homeostatic-based architectures is that the decision making systems are organized in different ways. AIBO [8] and KISMET [9] use a *hierarchical and top-down approach* to select behaviors. The strongest point of this approach is modularity. Hence, it is not only relatively understandable for operators in HRI studies but also straightforward to implement. In a contradictory approach, Bryson introduced the concept of "Behavior Oriented Design" with Parallel-rooted, Ordered, Slip-stack Hierarchical (POSH) reactive plans, which help the agent to behave *opportunistically* [10]. Specifically, each action is paired with a priority and preconditions to determine when to execute. This allows the agent to skip unnecessary steps in a sequence based on the conditions and also repeat steps if they fail or simply need repeating [24].

Emotions are also necessary to be implemented to naturalize the interaction between human and robots [9][11]. Fong *et al.* summarized the three basic theories to describe emotions in [12]. First, emotions can be characterized by discrete categories or basic emotions. The second theory uses continuous scales or basis dimensions such as arousal and valence. The third one is componential theory, which acknowledges both categories and dimensions. For instance, in KISMET, emotions are mapped in a three-dimensional space of arousal, valence, and stance [9]. Another robot, Probo, uses arousal and valence as its emotional space [13].

III. Conceptual design of Robee

Our social behavior controller, ROBEE, is designed following the psychological point of view with homeostatic drives due to advantages of this approach presented in Section II. Therefore, behaviors and emotions are selected based on the external stimuli and the process of maintaining the needs within an acceptable range. Since the social behavior controller is developed for HRI experiments, the architecture is designed with a high degree of understandability with subsystems as depicted in Figure 1. This section describes the behavior and emotion selection mechanisms in detail.

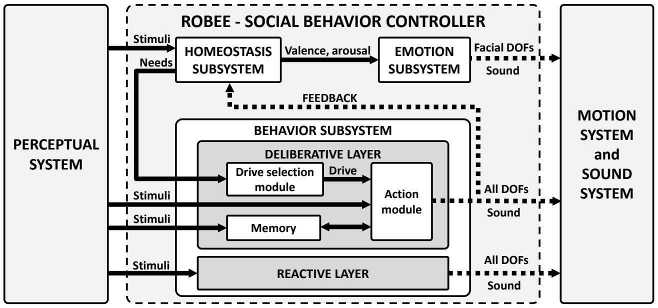
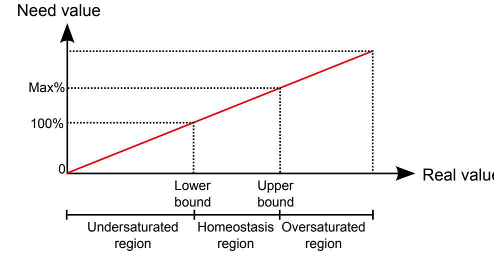
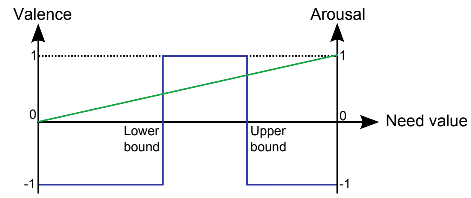


Fig. 1: Architecture of the social behavior controller ROBEE.



(a) The range of need with three regions: undersaturated, homeostasis, and oversaturated.



(b) The variation of valence (green) and arousal (blue) depending on the variation of need value.

Fig. 2: Relationships of real value, need value, valence and arousal in the homeostasis subsystem.

A. Homeostasis subsystem

The *homeostasis subsystem* manages the need values i.e the acceptability of the robot towards the real value of need, based on stimuli from the perceptual system and feedback of the selected actions from the *behavior subsystem*. These needs can be either physical (e.g, hunger, thirst, temperature) or psychological and social (e.g, being cared, or the need to perform a specific task or an activity). As shown in Figure 2a, each need spreads on a range consisting of three regions: undersaturated, homeostasis, and oversaturated. Since the measurement units of needs are different, we propose a linear relationship between real value and need value. At the lower bound, the need value is defined as 100%. When need values deviate from their acceptable ranges (homeostasis regions), drives are generated to trigger specific actions by the behavior subsystem. The feedback of actions pulls the need values back to the acceptable ranges.

The stimuli-actions-needs relationship is many-to-many. It means a stimulus or an action can change the values of several needs. For example, hot weather reduces the values of "Hydration" and increases that of "Body temperature". Or, the action of "Playing football" increases the need value of "Sport activity" but reduces that of "Energy".

A need value at time t is numerically calculated based on the influence values (A_j and S_k) and occurrences (Y_j and Y_k) of each related action (j) and stimulus (k) since $t = 0$ by the following equation:

$$N_i(t) = N_i(0) + \sum_{j=1}^{N_A} A_j Y_j + \sum_{k=1}^{N_S} S_k Y_k$$

where N_A and N_S are the numbers of related actions and stimuli of need i.

In the mean time, the *homeostasis subsystem* also calculates the valence and arousal values of each need as inputs for the *emotion subsystem*. The valence is linear with the need value while the arousal is positive within the homeostasis region and negative elsewhere (Figure 2b). The total values of valence and arousal are then mapped into a emotional space to generate appropriate facial expression.

B. Behavior subsystem

The *behavior subsystem* of ROBEE is modeled with two layers: deliberative layer for voluntary behavior, and reactive layer for involuntary behavior. Reflective layer is not discussed to reduce the complexity of the model.

1) Deliberative layer: This layer decides which behavior is executed at a specific moment depending on the variation of drive values which are associated to need values. As shown in Figure 3, the needs-drives relation is many-to-many and predefined for specific scenarios. For example, the drive "Thirst" is associated with the needs of "Hydration" and "Body temperature". However, a drive only has one satiator which decides the executed behaviors to satiate the needs.

A drive value at time t is calculated based on data from the *homeostasis subsystem* by the following equation:

$$D_j(t) = \frac{\sum_{i=1}^{N} \gamma_{ij} \cdot |N_i(t) - Ti|}{\sum_{i=1}^{N} \gamma_{ij}}$$

where γ_{ij} is the influence coefficient of need *i* to drive *j*, N_i is the value of need *i*, T_i is the threshold i.e lower bound in undersaturation and upper bound in oversaturation, and N is the number of needs. The drive with the highest value is selected to execute its drive satiator by the *drive selection module*.

Drive satiator is a set of Basic Reaction Plans (BRP) with priorities and preconditions, inspired by the opportunism of POSH reactive plans. Preconditions can be a set of stimuli or/and variables in *memory*. A BRP is selected if it has the highest priority among those with a complete satisfaction of preconditions by the *action module*. If some BRPs have the same priority, one of them is selected randomly. A BRP can be either a behavior or a set of behaviors. The selection mechanism within a BRP is identical with the BRP selection. This concept allows the robot to execute necessary steps instead of the whole sequence. Table I gives an example of drive satiator for "Thirst". If given an empty cup and a bottle of water, the robot pours water into the cup and skips asking

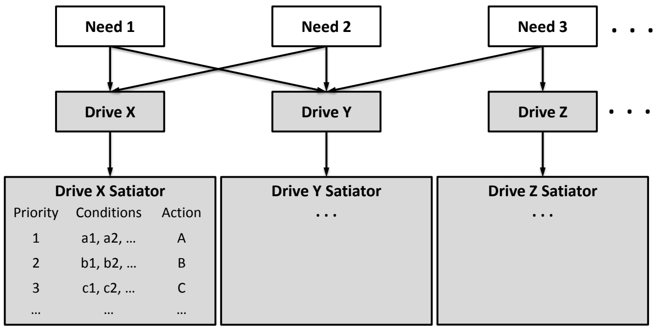


Fig. 3: The behavior hierarchy of ROBEE: needs, drives, and drive satiators.

Satiator	Priority	Preconditions	Behavior
Thirst	1	(have a cup of water)	Drink
	2	(have a empty cup) (have a bottle of water)	Pour water to the cup
	3	(have an empty cup)	Find a bottle of water
	4	-	Ask for a cup water

TABLE I: An example of a BRP of "Thirst" satiator.

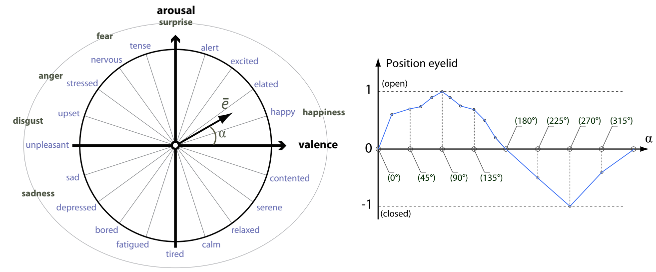


Fig. 4: The two-dimensional emotional space consisting of valence and arousal (left), and an example of controlling the position of the eyelid for each emotion (right). Figure reprinted from [13].

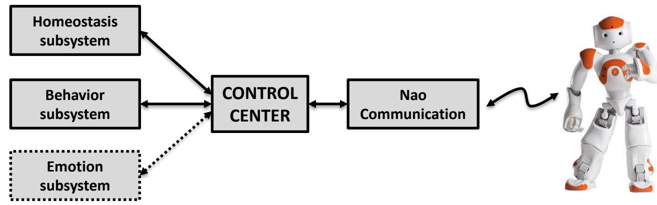


Fig. 6: Communication of GUI components. Emotion subsystem is not yet implemented.

for a cup of water. The drink behavior is then executed.

2) Reactive layer: In this layer, involuntary behaviors (or reflexes) are selected by direct links between stimuli and motor outputs. This mechanism allows the robot to immediately react to external stimuli and contributes to the understandability of the interaction. Direct links are modeled by a set of rules. For instance, if the robot suddenly feels hurt on its arm, it withdraws the arm and screams "Aww!!". Or, if an object is too close to its eyes, the eyes are closed.

C. Emotion subsystem

Emotions are selected by a valence-arousal emotional space based on the circumplex model of affect defined by Russell [14], which is also used in Probo [13]. This subsystem takes valence V_i and arousal A_i values of each need from the homeostasis subsystem to calculate the total values at time t by two following equations:

$$V_{total}(t) = \frac{\sum_{i=1}^{N} \alpha_i V_i(t)}{\sum_{i=1}^{N} \alpha_i} \qquad A_{total}(t) = \frac{\sum_{i=1}^{N} \beta_i A_i(t)}{\sum_{i=1}^{N} \beta_i}$$

where α_i and β_i are the weight factors of need *i* to contribute to the total values.

The two total values of valence and arousal are then mapped into the emotional space to create the emotion vector $\bar{e}$ as shown in Figure 4-left. The facial DOFs are controlled by the intensity of $\bar{e}$ and the angle α, e.g. position of eyelid in different emotions (Figure 4-right).

IV. IMPLEMENTATION

The social behavior controller presented in the previous section is implemented in the humanoid robot NAO. We provide a GUI which allows users to program particular scenarios for different HRI studies. Since ROBEE uses facial DOFs to express emotions while this ability of NAO is limited, the emotion subsystem is not implemented. Instead, we consider small behavioral tics (e.g. eye blinking, small head movements) and sounds in every action to express emotional responses in order to make the interaction more comfortable [25][26].

The GUI of ROBEE (Figure 5) is written in Microsoft Visual C# with winforms representing the subsystems: *homeostasis form*, *behavior form*, and *NAO communication form*. All forms communicate with each other via a "Control center form" for the ease of debugging or implementing new forms (Figure 6). Settings of each form can be saved in XML format and reloaded.

A. Homeostasis form

This form manages the needs of the robot, memory, and stimuli-action-needs links. When ROBEE runs, stimuli and actions from other forms influence the need values. The Stimuli-Memory-Needs Simulation tab helps user to manually activate stimuli or adjust need values.

B. Behavior form

This form consists of deliberative and reactive layer. In the deliberative layer, BRPs are displayed in a tree-view control. The reactive layer manages set of preconditions for reflexes. By clicking "START", the form calculates drive values based on need values, then decides the appropriate behavior.

C. NAO communication

This form connects ROBEE with NAO robot via wireless communication. Stimuli from NAO such as touches and vision are transfered to ROBEE. Also, selected behaviors are sent to NAO in order to execute corresponding actions.

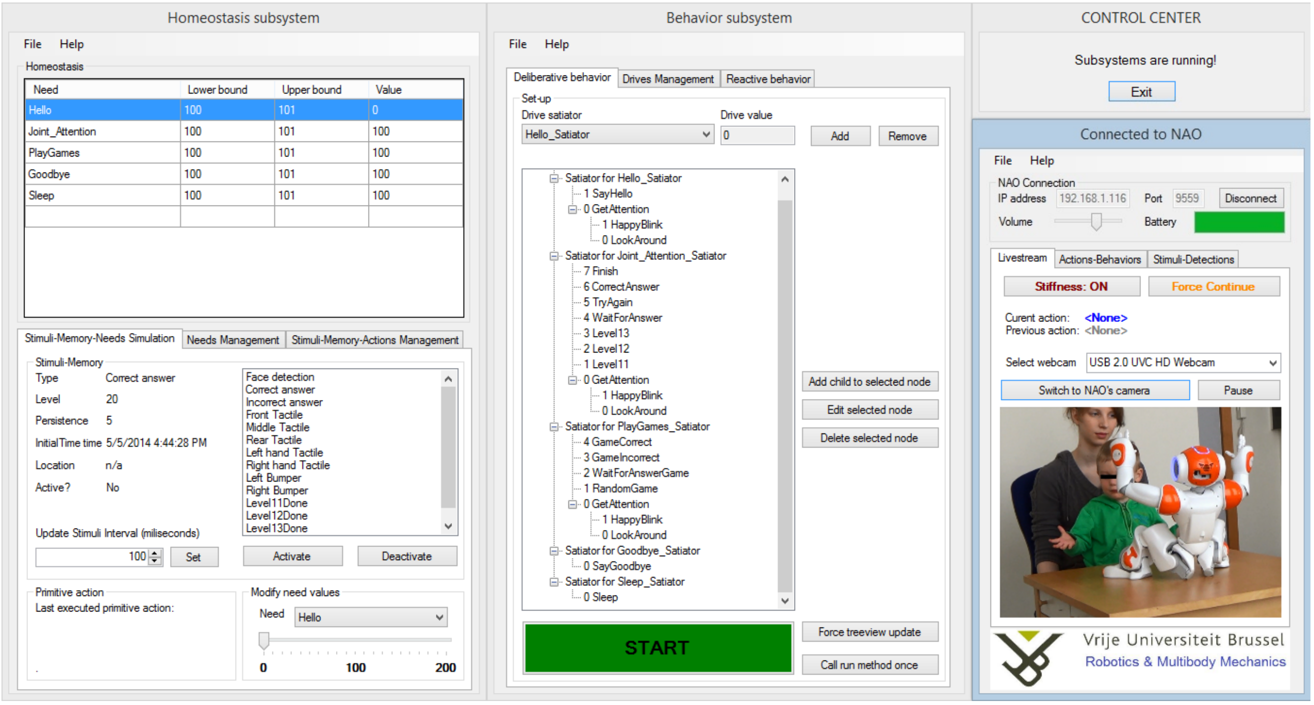


Fig. 5: GUI with settings for joint attention experiment scenario.

V. Joint attention experiment

In this section, we present a robot-assisted intervention to investigate joint attention skills of typically developing (TD) children through NAO using the social behavior controller ROBEE. The same experimental setting will be applied in the future to teach joint attention skills to children with autism.

A. *Aim of the experiment*

Joint Attention (JA) refers to a set of behaviors that serve to enable two partners to either vocally or non-vocally communicate about, or "jointly attend to" a third entity, object, or event [27]. Comparisons between children with autism and other populations of children showed that children with autism display deficits in eye-gaze shifting and gestural JA, and are less responsive to bids for JA [28][29]. Emerging research in robot-assisted therapy shows that robots can be used to elicit JA episodes for children with autism [30]. In this study, we do not include a robot in the therapeutic setting to replace therapists, but to: (1) use the strengths of robots to facilitate and improve the therapy outcomes and (2) make the learning process more motivating, by developing attractive robot-assisted games that can enable autistic children to overcome their social impairments. As earlier mentioned, the intervention is first tested with TD children.

B. *Method*

A TD child (12-36 months old) sits on the lap of a caregiver to interact with the robot as depicted in Figure 7. The interaction includes imitation games, touching NAO body parts, and singing with NAO. During the interaction, NAO switches the child's attention to different objects on the table, left-right, and left-right behind. The level of prompt varies

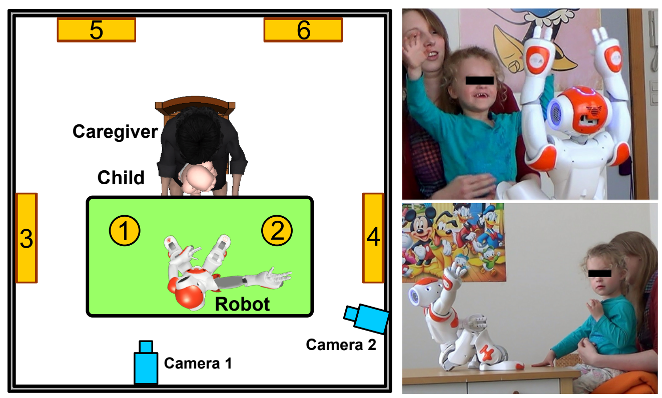


Fig. 7: The experimental room for child-robot interaction is arranged with objects on table and wall sides.

from easy mode (verbal, pointing, gaze) to medium mode (pointing, gaze) and hard mode (gaze only). The interaction is recorded by hidden cameras for analysis purpose.

C. *Using* ROBEE *to execute the scenario*

As earlier presented, ROBEE decides behaviors based on the process of maintaining the needs in an acceptable range. Following the experimental sequence, we define five needs correlated to five drives: Hello, Joint attention, Play games, Goodbye, and Sleep. All links (e.g need-stimulus-behavior) and associated numerical values are defined by the therapist. Figure 8 shows the variation of drive values in a sample test. At the beginning ($t = 0$), the need "Hello" is undersaturated and triggers drive "Hello" to execute the action "Say Hello" if a child's face is detected. After a short introduction, drive value of "Play games" is up ($t = 9s$) to execute a random

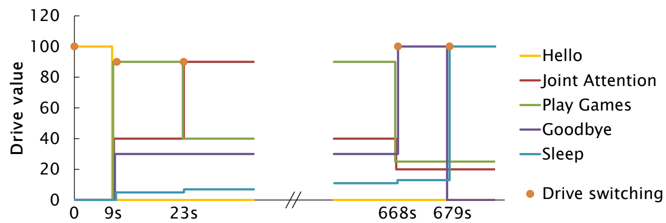


Fig. 8: Variation of drive values in a sample test. Dots represent the moments of drive switching.

game, e.g hands up (Figure 7-top-right). Following the same principle, after playing game ($t = 23s$), the robot needs to execute a JA task e.g pointing to the right (Figure 7-bottom-right). The child keeps playing and doing JA tasks until he or she finishes the highest level of prompt. After that, the drive "Goodbye" is increased to activate the action "Say goodbye" to the kid ($t = 668s$) and then goes to sleep mode ($t = 679s$).

In contrast with the traditional WoZ method in which the robot is remotely controlled by an operator, ROBEE helps the robot to select behaviors automatically. Hence, manual work is significantly reduced and the therapist can focus more on the interaction. During the learning task, the therapist can modify the need value to correct the behavior of the robot if he or she thinks the current behavior is not appropriate.

VI. Conclusion and Future work

We propose the design of ROBEE, a social behavior controller for robots in HRI experiments. Following the homeostatic drive concept, emotions and behaviors are selected based on a process of maintaining physical and psychological needs within an acceptable range. The decision making architecture is organized by combining the hierarchical approach and POSH reactive plans. Therefore, a specific behavior is chosen depending on its priority and preconditions.

ROBEE is implemented in NAO robot with an easy-to-use GUI. Using this GUI, users can program different scenarios for their experiments with high-level behaviors. A joint attention study has been conducted with TD children. According to the therapists, the performance of ROBEE is acceptable compared to that of the WoZ method. Further experiments are needed for comprehensive evaluation. Since ROBEE is platform-independent, it can be implemented in various robot platforms in the future.

Acknowledgments

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