A Modular Interface Design to Indicate a Robot's Social Capabilities

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***Abstract* – This paper presents an intersection of human-like appearance, product design, and information design in order to systematically manipulate a robot's conceptual user interface design. The social robot 'Flobi' appears as an iconic cartoon-like character to mediate between users and application scenarios. Flobi's interface design consist of three visual dimensions to choreograph user expectations of the robot's capabilities, traits, and competences. First, the robot has dynamic facial features to display various emotional expressions. Second, the structural head design consist of exchangeable modular parts which are magnetically connected. Through the modular design the visual features of Flobi (e.g., hairstyle, facial features) can be altered easily in order to create various characters. Third, different clothing will prospectively be used to trigger the robot's social roles. All three dimensions of visual features are highly likely to have an effect on the evaluation of Flobi's traits and capabilities.**

***Keywords* – Social Robots, Industrial Design, Human Factors**

I. INTRODUCTION

To date, social robots are mainly designed to engage in social scenarios which are familiar to users. Specifically, robots mainly have to provide a social communicative functionality that the interaction feels natural and intuitive to those who interact with the robot. In this respect, a social robot is generally a specific kind of interface metaphor in order to provide human-like interaction patterns [1].

Roboticists usually design robots to appear lifelike in order to represent natural (i.e., familiar) behaviors. On the one hand, some social robots strongly appear human-like, because the goal is to create android surrogates of existing persons. On the other hand, many social robots appear rather zoomorphic, caricatured, or technical [2]. But even if social robots vary greatly in terms of appearance their aesthetic form is primary intended to follow a specific familiar function, because this likely enhances the machines' comprehensibility to guarantee an intuitive usage. To illustrate, a social robot acting in a kitchen might be designed like a kitchen aid whereby a robotic learning aid might rather be shaped to appear like a teacher in order to mediate a certain degree of expertise.

One possibility of displaying different functionalities by a robot's appearance is to consider exchangeable visual features which represent aspects of a specific expertise. Regarding the industrial design of the robot Flobi, exchangeable visual features have been conceptualized and implemented [3]. As depicted in Figure 1, Flobi generally appears human-like due to its facial features. These features were implemented because previous research has demonstrated that a certain degree of human-likeness in appearance is necessary to produce facial expressions that are intuitively understandable. In addition, human-like appearance increases likely a robot's predictability in terms of human-like behaviors.

Taken together, the design of Flobi consists of three dimensions: First, the implementation of unambiguously recognizable facial expressions. Second, a modular surface-design makes it possible to quickly alter Flobi's visual character. Third, dress codes are considered to signify the robot's social roles in order to increase the predictability of the its expertise.

Figure 1: The social robot Flobi

After outlining related research in Section II, I present the key aspects of Flobi's visual conceptualization in Section III. Section IV discuss the visual conceptualization and concludes this article.

II. RELATED WORK

In this chapter, I introduce into research on the appearance of social robots and related effects of such visual representations. Moreover, I give a short introduction into relevant principles of iconic communication with regard to information design. These principles illustrate how specific information can visually be implement into objects as well as interfaces.

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2.1 Appearance of Social Robots

Originally, the meaning of the term ‘automaton’ implies autonomous beings having the ability to move on their own. For instance, Vausanson’s flute and tabor player and Wolfgang von Kemepelen’s famous chess player, ‘The Turk’, designed in the mid 1700s, are early encounters between lifelike forms and machines. Both machines invoked on people’s projections and expectations due to the behavior displayed by their lifelike form. Even today, social roboticists connect form and function in an attempt to develop lifelike social robots [4]. Thus, one general objective of social robotics research is to create robots that engage in social scenarios which are familiar to users. Given this objective, robots have to provide a social communicative functionality that is natural and intuitive to those who interact with the robot.

Social robots vary greatly in terms of appearance to indicate specific behaviors or applications. Some social robots appear highly anthropomorphic while others appear rather zoomorphic, caricatured, or functional. According to [2] an anthropomorphic appearance is recommended to support meaningful interactions [5] with users because many aspects of nonverbal communication are only understandable if expressed in similarity to a human-like body. For instance, emotional displays are highly iconic to emotional displays of human beings. Zoomorphic robots are intended to look like their animal counterparts to support the idea that an observer expects the robot to behave like an animal. In some cases this might be helpful to communicate the functional limitations of a social robot. To illustrate, a dog only partially understands human speech, but maybe this represents today’s recognition rates of current speech recognition software [6]. Robots with a caricatured appearance are mainly designed both to not elicit any expectations based on familiarity and to focus on specific attributes like mouth (i.e., speeking) or eyes (i.e., seeing). Finally, functional shaped robots are designed in a technical manner to illustrate their ultimate technical functions. This functional approach corresponds in a certain respect to the claim by Sullivan [7] that ‘form ever follows function’. In this case, the robot-designer expects that the user is able to understand capabilities of the robot by looking at its technical features.

Nevertheless, an human-like appearance matches probably best with the idea to implement artificial human-like behaviors to support intuitive interaction patterns. But in how far does an anthropomorphic appearance of robots affect the assessment of them? Specifically, recent research has shown that human-likeness of agents relates highly to the phenomenon of anthropomorphism.

2.1.1 Anthropomorphism

Anthropomorphism entails attributing human-like characteristics, properties, or mental states to real as well as imagined non-human agents and objects [8]. According to the familiarity hypothesis [9], people draw anthropomorphic inferences, because it allows us to explain things we do not understand in terms that we do understand – and we best understand ourselves as human beings.
However, the ‘Three-Factor Theory of Anthropomorphism’ [8] claims that the extent to which people anthropomorphize is determined by three general factors: First, *Effectance Motivation* describes the need to interact effectively with one’s environment. Attributing human characteristics and motivations to non-human agents increases the ability to make sense of an agent’s actions and consequently reduces uncertainty. Second, *Sociality Motivation* describes the need and desire to establish social connections. To illsutrate, when people feel lack of social connection they anthropomorphize objects more strongly. They do so to satisfy their need for affiliation. Finally, *Elicited Agent Knowledge* serves as a basis for induction primarily because such knowledge is acquired earlier and is more detailed than knowledge about non-human agents or objects. As a result, the more human-like an object appears, the more do people probably use themselves as a source of induction when judging non-human agents.

The key role of human-likeness in appearance has been demonstrated in an experiment by [10]. These authors conducted an fMRI study with three different robot targets which differed in their degree of human-like appearance. Participants’ brain activity was measured during playing an interactive game (.i.e., Prisoners' Dilemma) with these robots. The results showed that the degree of human-likeness had significant effects on the participants’ cortical activities associated with Theory of Mind (ToM) and their judgments of the different robots. Summing up, the more human-like an interaction partner appears, the more do participants speculate implicitly about the robot’s intentions. Moreover, it has been shown that the quantity of facial features implemented in a robot affect perceptions of human-likeness [11]. But in addition, faces imply various qualities which have effects on judgements. Specifically, due to the fact that a face continuously conveys information especially poor designed faces may cause negative attitudes towards an artificial agent or a robot [12].

2.1.2 Qualities of Facial Appearance

A vast body of research has shown that people attribute more positive traits to attractive people than to unattractive ones. [13-16]. To illustrate, attractive humans are commonly judged as warmer, kinder, stronger, more sensitive, interesting, poised, modest, sociable, and outgoing [13]. Moreoever, even babies prefer playing with attractive puppets [17]. Importantly, [18] suggested that an attractiveness bias is also applicable to objects. Further, there is evidence that unattractive objects can elicit uneaseness. This phenomenon is wellknown as the ‘uncanny valley’ hypothesis [19]. Such attributions are particularly true for faces with abnormal facial features (e.g., with regard to a bigger eye size of 150%). This suggests that the human visual system is particularly sensitive to cues indicating human-likeness [20].

However, not only does attractiveness or human-likeness of a face influence social perceptions. This is also true for babyfacedness. People with babyfaced facial features (e.g., curved forehead, large eyes, small nose and chin) are characterized as warmer, more naive, submissive, less dominant, and less competent than mature-faced counterparts [21]. Regarding Flobi’s appearance, we designed the head babyfaced in order to both facilitate human-robot interactions and display the limitations regarding the robot’s limited skills. Additionally, a modular design has been realized in order to modify the users’ evaluations of the robot's capabilities. The concept of how to systematically implement modular parts was mainly inspired by principles of information design and iconic communication.

2.2. Iconic Communication

To date, iconic communication systems often become valuable as new information systems call for designs that cut across language barriers. Therefore, iconic communication is an interesting source of inspiration when designing novel electronic interfaces such as social robots. Principles of iconic communication are universal and they are almost not tied to unique features of a particular language or culture [22].

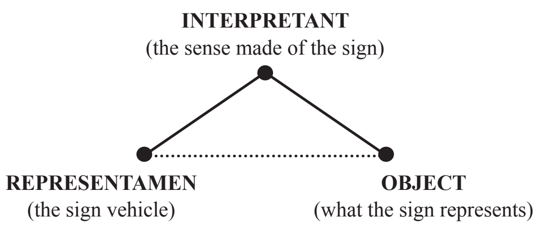

Figure 2: Sign relations according to Peirce. The dotted line means that there does not have to be any direct relation between the form of the sign and what it stands for

Generally, any information is mediated by signs and the concept of signs is essential to understand iconic communication: "A sign... [in the form of a representamen] is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, or perhaps a more developed sign. That sign which it creates I call the interpretant of the first sign. The sign stands for something, its object. It stands for that object, not in all respects, but in reference to a sort of idea, which I have sometimes called the ground of the representamen" [23] (see Figure 2). Furthermore, Peirce distinguished three general types of representamen: First, *indexical* signs denote their objects by virtue of an actual (physical) connection involving them (e.g., footsteps are connected to a living creature, smoke is connected to fire). Second, *symbolic* signs are connected to the represented objects by convention (e.g., words or language in general). Third, *iconic* signs represent objects by their similarity (e.g., photograph, natural drawing). Furthermore, Peirce then again divided icons into three subtypes: images, diagrams, and metaphors. Evidently, icons are naturally related to visual communication.

By using the term 'iconic communication system' I refer to a systematical combination of several icons to derive more specific meanings. To illustrate, I introduce into one specific aspect of the 'International System Of TYpographic Picture Education (ISOTYPE).

ISOTYPE [24] was basically invented in the 1920s by the sociologist Otto Neurath and the designer Gerd Arntz to visualize social and economical facts particularly with regard to facilitate the understanding of complex data for less educated people. Beyond that, ISOTYPE was intended to support foreign people having intuitively access to specific knowledge. To illustrate, icons at airports are richly implemented to help foreign

Figure 3: In ISOTYPE ethnic groups are demonstrated systematically by various iconic head types

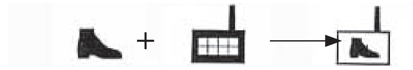

Figure 4: In ISOTYPE a combination of the visual items 'shoe' and 'factory' means a 'shoe factory'

people finding luggage, toilets, exits etc. With the invention of ISOTYPE there has been established new standards for presenting data and it fundamentally influenced several topics in the field of information design and interface design as well.

Neurath and Arntz created a limited number of icons for international use that should be readable without using further descriptions. At a first glance, an icon created ISOTYPE displays only the most important details of the represented object – in a way that it is just identifiable. At a second glance, visual attributes are used to elicit specific meanings of the object. To demonstrate, in Figure 3 there are circles representing human heads and, most importantly, different hats representing ethnic groups.

Such combined icons can be used to signify their relations in order to initiate more specific meanings. To illustrate, in Figure 4 a visual combination of 'shoe' and 'factory' simply is a 'shoe factory'. Such combined icons are frequently used in the field of interface design. For instance, *Susan Kare,* who created the interface of the *Macintosh Operating System* [25], differentiated on a first dimension between a general icon representing 'documents' and a prictograph representing 'applications' (see Figure 5). On another second dimension she connected additional 'task-icons' (e.g., text, draw, paint) to the documents and applications to categorize specific types of them. This schema supports users to quickly recognize the interface's objects. According to these concepts of combined icons, three dimensions of exchangeable visual parts were implemented to implicitly choreograph the users' perceived capabilities of the robot.

III. VISUALIZATION OF FLOBI

According to previous research [11], the extent to which a face is perceived human-like depends on the quantity of facial features. To realize a high degree of human-likeness, Flobi's facial features include eyes, eyelids, lips, ears, eyebrows. However, with regard to qualities of these features, Flobi appears cartoon-like with a certain similarity to humans to trigger natural interactions. Additionally, the robot appears babyfaced that people potentially

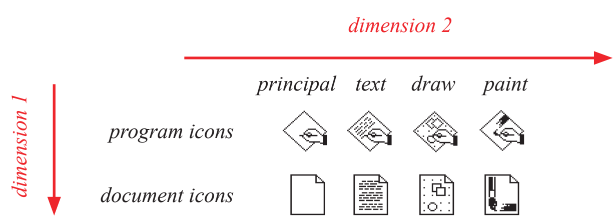

Figure 5: Icons of the first Apple Macintosh System

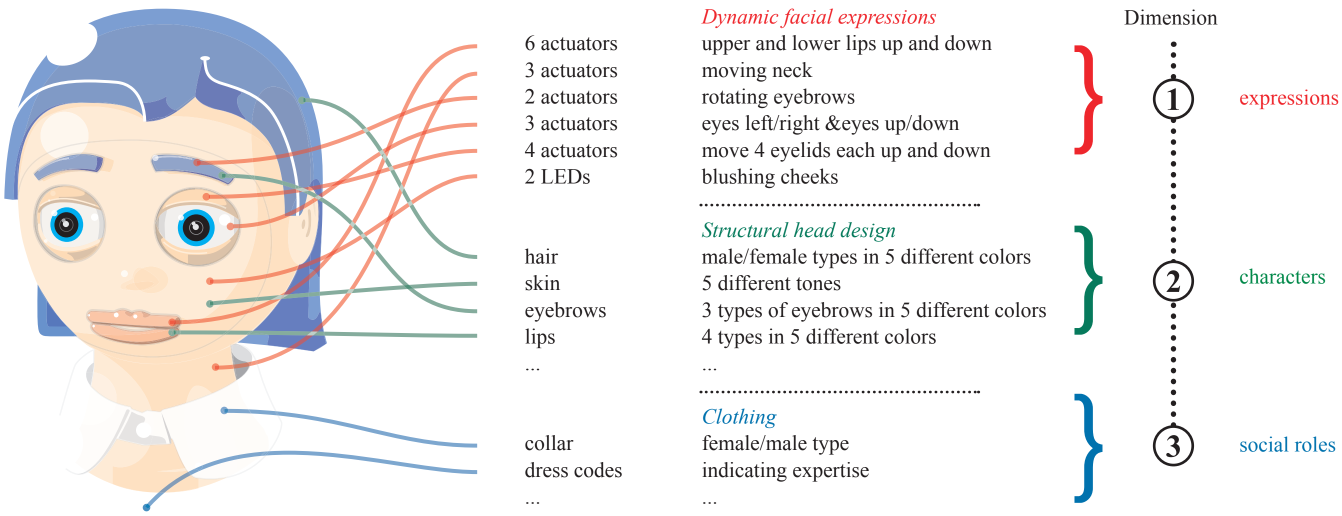

Figure 6: Iconic Communication with three dimensions of dynamic features

judge the robot to be submissive, more naive, and social warmer. Consequently, Flobi has relatively large eyes, a small chin, small lips, a small nose, and a round head shape similar to a baby's head [21]. Moreover, no technical junctions are visible in order to have a consistent character design and to avoid the aforementioned 'uncanny valley' [20].

Additionally, the size of the facial features is meant to signify a match between form and the product's actual function: The user shall infer Flobi's capabilities from its appearance. To give a visual indication of the robot's functional capabilities, Flobi has emphasized large eyes due to comparatively good visual capabilities, normal ears due to available hearing capabilities, and a small nose to indicate that Flobi does not have any olfactory capabilities. Furthermore, characters in computer games often have large eyes to improve the readability of attention – the direction of large eyes compared to small eyes is more likely to be recognized [26].

One of the significant issues that arises when we want to match the users' expectations with regard to different application scenarios is the conceptualization of exchangeable visual cues which can be altered dynamically. Specifically, Flobi has principally been developed to engage within various scenarios. Currently the robot is used in an emotional scenario [27] and in a sports scenario to support astronauts performing their daily physical training [28]. In order to use the robot in further scenarios, an iconic system of three dimensions was conceptualized (see Figure 6): First, the robot has the capability to dynamically display various facial expressions. Second, all perceivable parts of Flobi's head design are easily exchangeable. Finally, visual cues of dress codes will be used to initiate schemata of expertise.

3.1 Dimension 1: Displaying Facial Expressions

Altogether, Flobi has 18 degrees of freedom to display facial expressions, such as basic emotions like happiness, sadness, fear, surprise, and anger. Four actuators move the upper and lower eyelids, two actuators rotate the eyebrows, three actuators move the eyes, three actuators move the neck, and finally, six actuators were implemented to animate the robot's lips. Furthermore, by means of four LEDs, red or white light can be projected onto Flobi's cheek surfaces in order to prospectively indicate either shame or healthiness. Displaying shame is an interesting feature, because it signifies a uniquely human emotion and has not yet been investigated deeply in robotics.

Because product design requires covering technical conjunctions, we developed a 'hole-free' robot head. It was particularly challenging to meet this requirement with regard to Flobi's lip movements. In few robots LED technology is used to project lips onto the face. Nevertheless, we decided against LED technology to display the robot's lips because of the unnatural appeal of LEDs. Instead, Flobi's upper and lower lips consist of neodymium magnets that can be actuated separately. Behind the robot's mask, coupled magnets are actuated on sliding axes, with the motion range overlapping between upper and lower lips. The large and overlapping motion range makes it possible to realize a relatively natural facial expression, because the corners of Flobi's mouth are not fixed. Flobi differs from some prominent social robots in this regard (e.g., the Philips iCat [29]), because in these robots, the corners of the mouth are commonly fixed. Flobi's lip actuators can lift the corners of the mouth to form natural smile without exposing holes or hardware.

In a first study regarding the readability of emotional displays, it has been shown that participants are able to distinguish a set of signified facial expressions. The face with its actuated features makes it possible to display basic emotions as happiness, sadness, fear, surprise and anger (see Figure 7). However, are users able to classify these distinct emotional states correctly? This was tested in an online survey [31] with 259 participants (160 female, 90 male) who evaluated the emotional

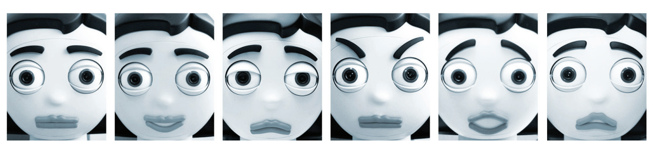

Figure 7: Emotional displays of Flobi. From left to right: neutral, happiness, sadness, anger, surprise, and fear

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displays of Flobi. The participants were ranging in age from 17 to 67 years, with a mean age of 27.7. Conceptually replicating [30], participants were presented with five images of the robot in a randomized order. The images depicted five basic emotions displayed by the robot. Subsequently, participants had to indicate which of the emotions would be portrayed by the robots.

The results demonstrated that Flobi's displays were almost readable: The participants were able to classify displays of sadness (99,2%), happiness (83,3%), anger (81,2%) and surprise (54,5%) relatively correct. The display of fear (33,5%), however, was recognized less well, because obviously, many participants mistook surprise for fear (51,2%). Moreover, it is likely that these displays will be even more readable when they are presented in a certain context. Taken together, by means of this 18 mechanically actuated features Flobi is capable of displaying a variety of meaningful expressions that represent the product's communicative states and intentions.

3.2 Dimension 2: Modular Head Features

Psychological research has shown that even subtle visual cues can lead to a target's categorization, for example, in terms of the person's age, race, or gender. This categorization occurs automatically within individuals and activates knowledge structures such as stereotypes or social roles. Specifically, stereotypes and social roles imply certain sets of behaviors that are expected of a person [32]. For this reason, Flobi's consist of exchangeable modular parts (see Figure 8). Because the modular approach makes it possible to alter Flobi's appearance quickly and flexibly, this robot can theoretically be used as research platform to study HRI in a wide range of different contexts.

By means of the modular conceptualization of Flobi's head, it is possible select specific features to manipulate users' expectations and perceptions of the robot. Practically, all modules of the robot head can be combined as needed. This is possible because most of the head's features are attached to the core by means of neodymium magnets. To build one specific character a set of ten parts in total is required.

Two main parts, a front head and a front neck, are screwed onto the technical core (see Figure 8-6). The face and the back part of the head are connected to the front head part using neodymium magnets. Flobi's back neck is connected to its front neck part using magnets as well. All these parts are available in human-like skin tones of varying shades (see Figure 8-2). The hair parts as well as the upper and lower lips are connected to the head using magnets, too. Flobi's eyebrows can be plugged into an actuator behind the face mask.

In a preliminary study [33] regarding the variable modules, we found that different hair types affect stereotypically knowledge structures in subjects. 60 participants were tested, ranging in age from 19 to 38 years. We used two different hair modules to create a long-haired 'feminine robot' and a short-haired 'masculine robot' (see Figure 9). As predicted, the long-haired 'female' version of Flobi was perceived as more feminine than the short-haired one. The participants were then asked to evaluate the 'gendered' robots in terms of gender-stereotypical traits and the robot's suitability for typically female vs. male tasks. In this manner, the participants rated the robot on a 7-point Likert scale with regard

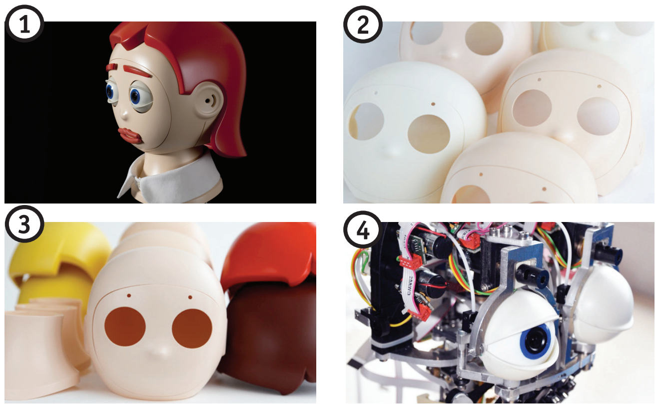

Figure 8: Exchangeanble parts of the robot's head: (1) female Flobi combined with red hair, (2) skin tones, (3) a set of different head parts, (4) technical corpus

to six stereotypically female traits (e.g., friendly, trusting, polite) and six stereotypically male traits (e.g., authoritative, aggressive, dominant). The results showed that the male robot was perceived as possessing more stereotypically masculine traits than the female robot whereas the female robot was perceived as slightly warmer than the male robot.

Furthermore, the participants evaluated the robots' suitability for pretested typically female tasks (childcare, household maintenance, after-school tutoring, patient care, preparing meals and elderly care) and typically male tasks (transporting goods, repairing technical equiptment, guarding a house, steering machines, handcrafting and servicing equiptment). The results show that typically female tasks were perceived as more suitable for the feminine robot relative to the masculine target – and vice versa. Participants perceived the female robot as being more suitable for stereotypically 'female tasks' than the male robot. Vice versa, the male robot was perceived as being more suitable for 'male tasks' [more detailed information regarding this experiment in 33]. Taken together, due to the modular design (in this case a hair module), we are able to create distinct robot characters whose gendered appearance affect the participants' expectations about the robots' personality and expertise.

3.3 Dimension 3: Dress Codes

According to Goffman [34] life in society is a sort of 'theater'. That is, there is a connection between the kinds of acts that people put on in their daily life and theatrical performances. In daily interactions as well as in theatrical performances the 'actors' (individuals) are on 'stage' in front of their audiences. However, people display their social roles not only behavioral, in addition they automatically use cues such as dress codes by which other people (audiences) are able to identify their specific

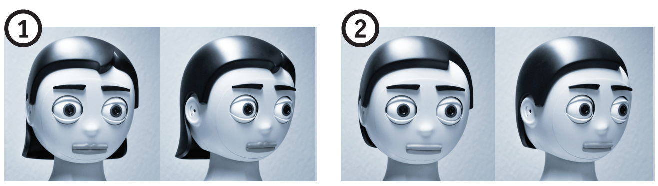

Figure 9: Flobi with female (1) and male (2) hair module

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social roles. Commonly, people wear a certain set of clothes that signify their social role. This has been evolved due to different requirements of specific domains. To illustrate, most sports and physical activities are practiced wearing specific clothing, for practical, for comfort, or for safety reasons. In addition, clothing performs a range of social and cultural functions, such as individual, occupational and sexual differentiation, and social status. Probably, in almost all societies, dress codes reflect standards of modesty, religion, gender, and social status. Dress codes may additionally function as a sort of adornment and an expression of personal taste or style. However, triggering role-specific information is likely possible by considering role-specific dress codes.

Role specific information such as clothing codes have already been applied to virtual agents in order to alter a user's expectations. Virtual agents wearing role-specific clothing were expected to behave appropriate in terms of that roles [35]. Therefore, it is highly likely that context-specific dresses in social robotics also have an effect regarding the assessment of robots as well. To investigate effects of dress codes in robotics, we drew a set of sketches (examples in Figure 10) which will be tested experimentally in order to have knowledge how to choreograph the perceived expertise of a robot by using such codes.

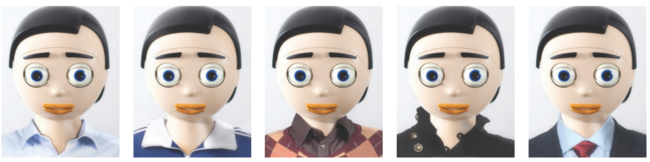

Figure 10: Examples of dress codes applied to Flobi

IV. DISCUSSION & CONCLUSION

Flobi is a cartoon-like social robot with a certain degree of human-likeness. In order to activate natural interaction patterns, one essential feature of Flobi is that it is capable of displaying distinctive meaningful facial expressions. Participants in a pilot study were intuitively able to almost distinguish among five displays of basic emotions. Furthermore, according to principles of information design Flobi's head consists of exchangeable modular parts to instantly arrange different characters. This set of characters was conceptualized to initiate expectations in terms of stereotypes. Regarding the modularity, it has been shown by means of statistical analysis that even minimal hair cues led people to judge the robot differently. An expansion of another head parts including additional visual attributes is work in progress. In addition to exchangeable modules, different clothings are conceptualized to indicate Flobi's social role with regard to the its expertise.

Taken together, there currently exist three visual dimensions of dynamic features to modify Flobi's appearance: (a) movable facial expressions, (b) modular head parts, and (c) exchangeable clothings.

Fundamentally, this concept of exchangeable visuals is not a novel one since it has successfully been implemented in many products such as cell phones (e.g., different skins of preference), cars, and toys (e.g., Playmobil® figures consist of different clothings as well as facial features to indicate specific scenarios of play). In contrast to today´s commercial products, this concept has never been applied to robotic products with the ability of social interaction before – even though it is an interesting feature due to the fact that there is probably an open field of various unknown application scenarios.

The option to exchange visual features enables us to systematically do research on the appearance of robots. Most of today's social robots have a fixed appearance that allows researchers only to investigate explicitly one specific character. By contrast, the modular design makes it possible to investigate dozens of differently created characters in order to understand the effects of appearance in this field of robotics.

Moreover, a modular robotic design involves potential users into the process of design and enables them to arange their own characters of aesthetical preference. It is likely that people have a bias towards specific characters. To illustrate, some people generally prefer to have female agents while others might prefer male ones. This way, the method of modularity is a first step towards giving the people the ability to build their own enjoyable robotic characters.

The conceptualization of the modular design was mainly realized to indicate familiar knowledge structures in order to choreograph people's mental models with regard to the robot's apparently capabilities. To illustrate, a social robot whose job is to support technical maintenance will probably be perceived as having more expertise if the robot has typically a male appearance wearing a repairman's clothing. This suggestion is supported by our first findings that even the exchange of minimal hair cues affect the user's perception. However, regarding the modular concept there are three open questions: First, the results of our experiment are currently limited to first impressions of the robot. Accordingly, it might be possible that individuals change their attitudes toward robots due to iterative interactions. Additionally, we are not able to predict how the robot's actual behavior affects the expectations people have due to their first impressions. Second, with regard to dress codes we first have to conduct experiments whether people ascribe or not specific capabilities due to such codes. Third, the presented studies in this article are limited to the evaluation of images displaying robots. The embodiment of a product might have an effect on the perception and the judgement of social robots as well.

Unfortunately, from an engineering point of view, Flobi is currently far away from being a commercial product. Up to now, two hardware prototypes have been realized mainly to test the functional issues in terms of technical capabilities – a third prototype is work in progress. Therefore, it has not been tested to which extent the aesthetical modularity of robots might be effective in the field of commercial entertainment robots as well. Therefore, a vast body of additional research is needed to draw further conclusions with regard to the engineering, aesthetical, and practical aspects of the modularity concept.

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