All Robots Are Not Created Equal: The Design and Perception of Humanoid Robot Heads

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ABSTRACT
This paper presents design research conducted as part of a larger project on human-robot interaction. The primary goal of this study was to come to an initial understanding of what features and dimensions of a humanoid robot's face most dramatically contribute to people's perception of its humanness. To answer this question we analyzed 48 robots and conducted surveys to measure people's perception of each robot’s humanness. Through our research we found that the presence of certain features, the dimensions of the head, and the total number of facial features heavily influence the perception of humanness in robot heads. This paper presents our findings and initial guidelines for the design of humanoid robot heads.

Keywords human-robot interaction, social robots, interaction design, design research

INTRODUCTION AND MOTIVATION

Advances in computer engineering and artificial intelligence have led to breakthroughs in robotic technology. Today, autonomous mobile robots can track a person's location, provide contextually appropriate information, and act in response to spoken commands. In the future robots will assist people with a variety of tasks that are physically demanding, unsafe, unpleasant, or boring.

Because they are designed for a social world, robotic assistants must carry out functional and social tasks. Much of the research in robotics has focused on improving the state of the current technology. Our goal is to match the technology to the needs of users. Although the technology exists to build a robust robotic assistant [26], we lack a principled understanding of how to design robots that will accomplish social goals.

The goal of our project is to conduct applied research into the cognitive and social design of robots. If robots are going to be intelligent social products that assist us in our day-to-day needs, then our interaction with them should be enjoyable as well as efficient. We are interested in issues of product form, behavior, and interaction in social robots as they relate to accessibility, desirability, and expressiveness. From our research, we will develop models of human-robot interaction that support appropriate and pleasant experiences and use these models to create guidelines for the design of assistive robots.

This research is important for the fields of interaction and product design, human-computer interaction, and robotics. Human-robot interaction is a new area of research and the impact of design on this field has yet to be understood.

Most of the research efforts in human-robot interaction have not been focused on design [11-13, 27]. Relevant work has been done in related areas such as anthropomorphism [9, 20, 22], computers as social actors [22, 23], facial interfaces [19, 28 - 30], and believable agents [7, 8, 25]. Although basic and tacit knowledge from other areas of research and design can be brought to inform human-robot interaction, core design research is still

. Pearl, our Research robot

Figure 3. ASIMO, an example of a Consumer Product robot

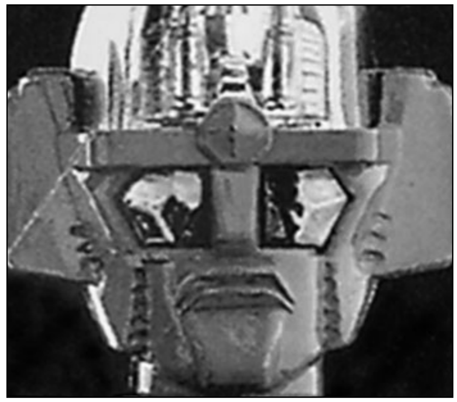


Figure 4. The Transformer, an example of a Fictional robot

to understand and articulate
ges of interacting with and
ng social robots.

obotics researchers are pursing a
oid robot form as the most
iate form for a social robot [11- 13,
ese researchers have assumed
ly that the head will be the primary
f human-robot interaction. While
umption has yet to be scientifically
we have chosen to pursue research
rea of humanoid robot heads for a
tic design goal: the design of a new
r our robot, Pearl.

as developed as part of the
ot project
www.cs.cmu.edu/~nursebot). Pearl
in both laboratory experiments and
ttings as part of our research into
robot interaction. We have re-
d Pearl's head to have modular
s. Modular features will allow us to
econfigure Pearl's head and conduct
experiments on the impact of facial
s and dimensions.

tial study was used to inform that
gn process. The findings were used
ify what facial features and
ions will be most important for us
control over and direct the
al design team in the creation of a
ad for Pearl.

OD

oid robot design is in its infancy
ch can be learned from a wide
ation of anthropomorphism. For the
this study however, we limited our
o existing humanoid robots. We
by collecting images of 48 robots from websites, books, and magazines. We sorted theses images into 3 categories: Research, Consumer Products, and Fiction. The Research category consisted of robots that have been created in educational and industrial research laboratories (n=18). Pearl is an example of a research robot (Figure 2).The Consumer Products category consisted of robots that have been manufactured to be for sale as actual functioning products (n=14). ASIMO is an example of a Consumer Product robot (Figure 3). The Fictional category consisted of robots from television, film, and toys (n=16). The Transformer is an example of a fictional robot (Figure 4).

Surveys

We used the images of the 48 robots to construct two paper and pencil surveys. One survey contained an image of the head and body of each robot. The other survey contained an image of each robot head only. In both surveys, participants were asked to rate each image on a 1 to 5 scale, from Not Very Human Like to Very Human Like. We solicited 20 participants for each survey. Participants either did the robot head or the whole robot survey, but not both.

The results for each survey were correlated to assess the validity of robot head scores. The two surveys were highly correlated, suggesting that our scores of the perception of humanness of robot heads are accurate and valid.

Robot Head Analysis

Using images of the 48 robots we collected, the heads were coded for the presence of eyes, ears, nose, mouth, eyelids, and eyebrows, and the total number of features present on the head. The heads were scaled to a height of 10 inches so that all of the measurements would be relative. The images of the face were measured to record the height/width ratio of each face; the percentage of the forehead region, feature region, and chin region, the size of the eyes, the distance between the eyes, and the width of the mouth (Figure 5).

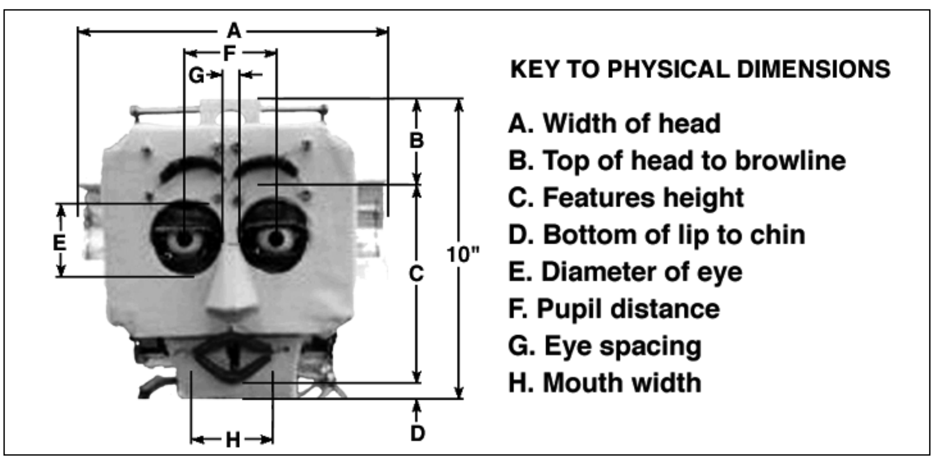


Figure 5. Diagram of the comparative physical measures — robot posed here is WE-3RIV All robot heads were scaled to 10" height

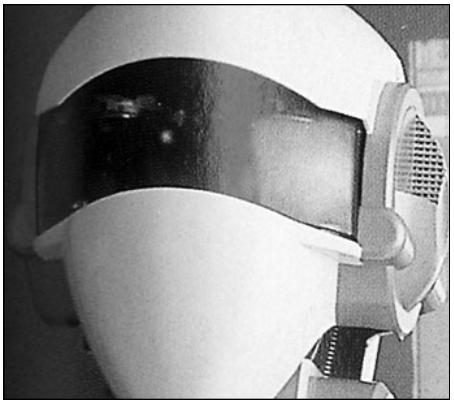


Figure 6. SIG, an example of a robot without facial features

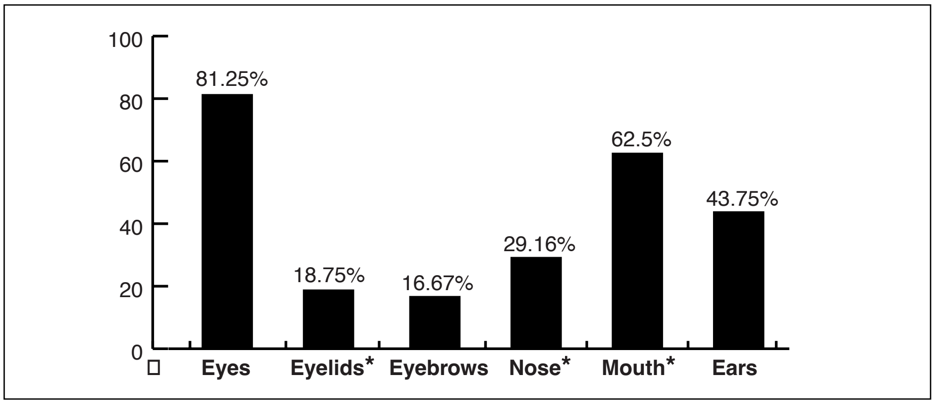


Figure 7. The presence and influence of features on robot heads
*** The presence of these features had a statistically significant effect on the perception of humanness**

Using the data from the head analysis and the robot head survey (we did not include the ratings from the whole robot surveys), we constructed two statistical models relating to the perception of humanness in robot heads: The Presence of Features and The Dimensions of The Head and The Total Number of Features and performed a regression analysis on these models to come to our findings.

FINDINGS

The Presence of Features

One would assume that all humanoid robots would have facial features but this is not the case. Of the 48 humanoid robots that we surveyed, six did not have any facial features. SIG is an example of a humanoid robot without any facial features (Figure 6). However, the presence of facial features is very important. The presence of specific facial features account for 62% of the variance in the perception of humanness in humanoid robot heads. The three features that increase the perception of humanness the most are the nose ($p < .01$), the eyelids ($p = .01$) and the mouth ($p < .05$) (Figure 7).

The Dimensions of The Head and Features and The Total Number of Features

The shape of a human head, the dimensions of facial features, and the distribution of those features on the head are fairly uniform in humans, but this is not the case in robots (Figure 8). We saw a similar variance in the width of the head relative to the height. None of the dimensions of the facial features are individually significant in the perception of humanness in robot heads. However, the total number of features on the robot's head is significant in the perception of humanness ($p < .01$). The more features that a robot head has, the more human like it will be perceived. The width of the head is also significant, in the perception of humanness ($p < .03$); the wider the head compared with the height, the less human-like it is perceived.

Robot Heads In Comparison To Human Heads

We were curious to know how much the dimensions of a robot's head differed from the dimension of human heads. We combined the dimensions of the facial features of the Mona Lisa, Michelangelo's statue of David, George Bush, and Britney Spears to develop prototypical human head. We realize that this is not an average head (such as has been constructed by Langlois & Roggman [17-19]). We chose these faces to make a composite from because they provide a general representation of the idealized human face.

We compared this prototypical human head to a somewhat human-like robot head and a very human-like robot head. For the very human-like robot head we chose the robot from Metropolis who was ranked the second most human-like of our 48 robots. For the somewhat human-like head we chose Lazlo, a research robot from MIT, who fell within our median range of humanness and was ranked 19th most human-like robot (Figure 9).

How Human-Like is Humanoid?

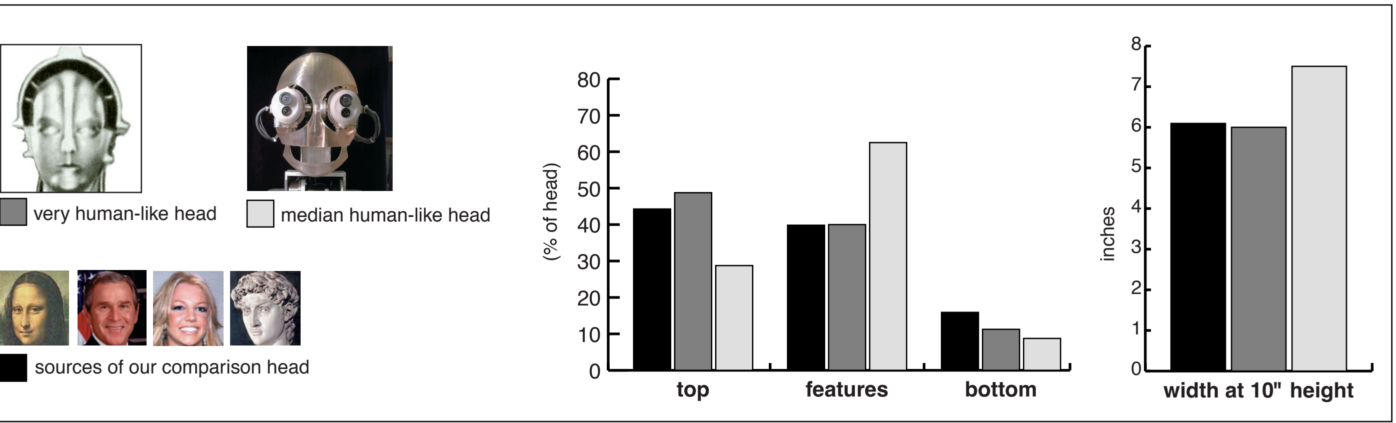
Although all of the robots included in this survey were classified as humanoid, the majority of them were not rated as being very human-like. The mean score on the scale of humanness for the robot heads was 2.74 (sd 0.68). This does not conflict with their classification as humanoid robots, for that simply means that their form resembles a human more than it resembles any other form. This does, however, raise the issue of how human-like a robot can be perceived by form alone. Humanness will be defined not only by form but interactions through expression, communication, and behavior.

The Importance of Design

As designers we would like to believe that the design of facial features is important in

	Minimum	Median	Maximum
Eye Diameter	0.25"	1.75"	4.75"
Pupil to Pupil	1.375"	4"	11.75"
Mouth Width	0.875"	3.75"	9.25"
Head Width	5.25"	9.63"	20"
Top	8.75%	35%	62.5%
Middle	28.75%	60%	100%
Bottom	6.25%	11.88%	27.5%

Figure 8. The dimensions of features on robot heads
Note: All dimensions are relative to the head at 10" height



9. Contrast of measures between our comparison human head, a very human-like robot head, and a median human-like robot head

ception of humanness. Not all robots esigned" facial features. Many oid robots express their human s only through the *suggestion* of s. However, designed features do significant effect on the perception anness ($p < .01$). Whether or not the s had been designed accounts for the variance in the perception of ness in humanoid robot heads. (Figure 10) is an example of a ith highly designed features, DB 11) is an example of a robot whose s are merely suggested.

nding suggests that in situations t is not possible or feasible to the actual facial features providing ions of those features, in effect nces for those features, may suffice ing an overall perception of ness in the robot head.

CATIONS FOR DESIGN

uman Should a Head Be?

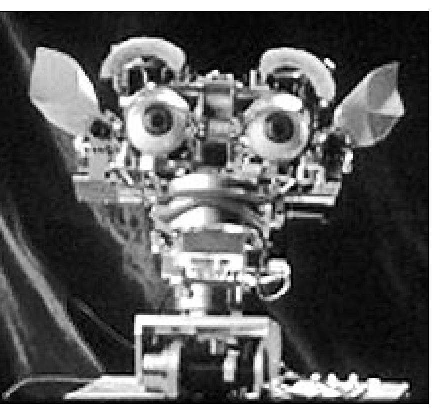
s a dual challenge in our design m. First, we must understand what of robot form lend themselves to being sufficiently human-like to carry on social interaction in an appropriate and pleasant way. Next we need to understand the aspects of the robot that need to remain robotic enough to clearly display the robot's non-human capabilities and emotional limitations.

Mashiro Mori developed a theory of The Uncanny Valley (Figure 12), which states that as a robot increases in humanness there is a point where the robot is not 100% similar to humans but the balance between humanness and machine-like is uncomfortable. Mori provides and example: "If you shake an artificial hand [that you perceive to be real] you may not be able to help jumping up with a scream, having received a horrible, cold, spongy, grasp." According to Mori there is a reasonable degree of familiarity that should be achieved and maintained in humanoid robots [24].

Between the three categories of Research, Consumer Product, and Fictional robots, Fictional robots are on average the most human-like and Consumer Products are on average the least human-like. Although the difference between the categories is not large, it is enough to suggest a trend in Consumer Product robots to appear more robotic than human. Whether this trend is due to the technical constraints of creating a robot for everyday use or reflects the actual preferences of users has yet to be determined and is an important topic for future research.

The relationship of the body to the head and the importance of the body in the overall perception of humanness is another important topic of inquiry. Although this study focused on the form of the head the body clearly plays a role in the perception of humanness.

We are working toward identifying the threshold of humanness that is most appropriate for social robots. We know from existing literature that the face is extremely important in scenarios of human-to-human interaction and we know how the human face functions in those scenarios [10, 14, 30]. However, a robot is not a human and its form will always be different



10. Kismet, a robot with designed atures

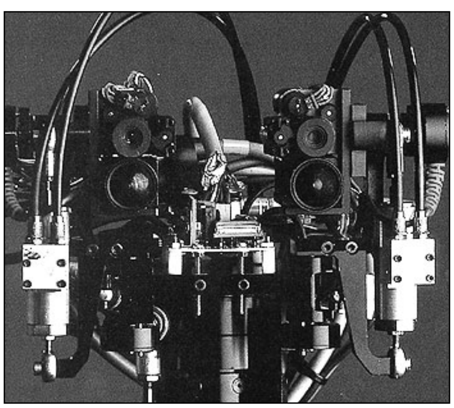


Figure 11. DB, a robot whose facial features are merely suggested

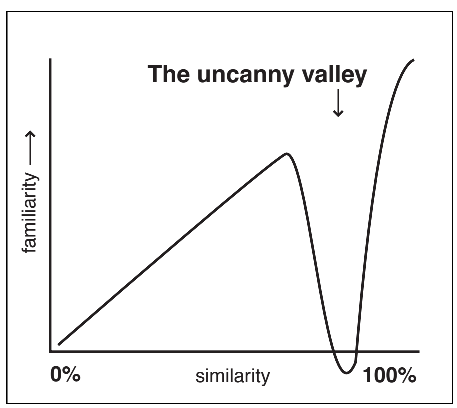


Figure 12. Mori's The Uncanny Valley, adapted from Reichard 1978

than that of a human. A need exists for a set of heuristics to define the appropriate design of a humanoid robot that interacts with humans.

Our research has led us to create a set of suggestions for the physical design of a new head for Pearl. It is important to note that this set of suggestions does not include the design of movement. These design suggestions for a robot head take into account three considerations: the need to retain an amount of robot-ness so that the user does not develop false expectations of the robots emotional abilities but realizes its machine capabilities, the need to project an amount of humanness so that the user will feel comfortable socially engaging the robot, and the need to convey an amount of product-ness so that the user will feel comfortable *using* the robot. Together, these suggestions create a balance between what we expect of a human, a robot, and a product for an effective design. We have executed these guidelines in the design of a new head for our robot Pearl (Figure 13).

DESIGN SUGGESTIONS FOR A HUMANOID ROBOTIC HEAD

1. Wide head, wide eyes

To retain a certain amount of robot-ness, by making the robot look *less* human, the head should be slightly wider than it is tall and the eye space should be slightly wider than the diameter of the eye.

2. Features that dominate the face

The feature set, from brow line to bottom of mouth, should dominate the face. Proportionally, less space should be given to forehead, hair, jaw or chin. This distribution is in contrast to a human's and combined with the size of the head, will clearly state the form of the head as being robot-like.

3. Complexity and detail in the eyes

Human eyes are complex and intricate objects. To project humanness a robot must have eyes, and the eyes should include some complexity in surface detail, shape of the eye, eyeball, iris, and pupil.

4. Four or more features

The findings from our study show that the presence of a nose, a mouth, and eyelids, greatly contribute to the perception of humanness. To project a high level of humanness in a robot these features should be included on the head.

5. Skin

For a robot to appear as a consumer product it must appear finished. As skin, or some form of casing is necessary to achieve this sense of finish. The head should include a skin or covering of mechanical substructure and electrical components. The skin may be made of soft or hard materials.

6. Humanistic form language

The stylized appearance of any product form is important in directing our interaction with it. To support the goal of a humanoid robot the head shape should be organic in form with complex curves in the forehead, back head and cheek areas.

FUTURE RESEARCH

The effect of interaction in the perception of humanness should not be underestimated. While this study was conducted with static images of robots isolated from any context and devoid of animation or interaction, our future research will conduct similar measures of humanness with physically present, animated, and contextually situated robots. We believe that interaction through speech and movement will greatly effect the perception of humanness in robots.
Our future research will also address robot forms that are not humanoid. We acknowledge that the importance of using a humanoid form is still an assumption that has yet to be proven. We plan to explore other robotic forms and their effect on facilitating social human-robot interaction. Finally, we plan on examining anthropomorphic forms and behaviors that exist in products other than robots.

CONCLUSION

This study showed that the presence of certain features, the dimensions of the head, and the number of facial features greatly influence the perception of humanness in robot heads. Some robots are much more successful in the portrayal of humanness than others. This success is due, at least in part, to the design of the robot's head. From these findings we have created and initial set of guidelines for the design of humanoid robot heads. Specifically, we have identified features and dimensions that can be used to modulate how human-like a robot head will be perceived. These findings should serve as a connection between ongoing robot research and the social products of the future.

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REFERENCES

1. Bates, J. The Role of Emotion in Believable Agents. *Communications of the ACM, 37* (7). 122-125.

2. Bates, B. *The Human Face*. BBC Worldwide Limited, New York, 2001.

3. Breazeal, C. and Velasquez, J., Toward Teaching a Robot "Infant" using Emotive Communication Acts. In *Proceedings of Simulation of Adaptive*

avior, workshop on Socially Situated ligence '98, (Zurich, Switzerland, 8), 25-40.

zeal, C. and Velasquez, J., Robot in ety: Friend or Appliance? In *eedings of Agents 99 Workshop on tion-based agent architectures*, ttle, WA, 1999), 18-26.

zeal, C. and Scassellati, B., How to d Robots That Make Friends and uence People. In *Proceedings of S-99*, (Kyonju, Korea, 1999).

ce, A., Nourbakhsh, I. and Simmons, he Role of Expressiveness and ntion in Human-Robot Interaction. *roceedings, AAAI Fall Symposium.* 1).

ell, J. *Embodied Conversational nts*. MIT Press, Cambridge, Mass., 0.

ell, J., Bickmore, T., Vilhjlmsson, nd Yan, H., More Than Just a Pretty : Affordance in Embodiment. In *eedings of 2000 International ference on Intelligent User rfaces*, (New Orleans, LA, USA, 0).

, A., Brennan, S., Laurel, B. and neiderman, B., Anthropomorphism: m Eliza to Terminator 2. In *eedings of Human Factors in puting Systems '92*, (1992), 67-70.

man, P. (ed.), *Emotion in the Human e*. Cambridge University Press, mbridge: UK, 1982.

manoid Interaction Lab, National itute of Advanced Industrial ence and Technology, Japan. //www.etl.go.jp/etl/robotics/ ects/Humanoid/

manoid Robotics Institute, Waseda versity, Japan. ://www.humanoid.waseda.ac.jp/

13. Humanoid Robotics Group, Massachusetts Institute of Technology, USA. http://www.ai.mit.edu/projects/humanoid-robotics-group/

14. Hassin, R. and Trope, Y. Facing faces: Studies on the cognitive aspects of physiognomy. *Journal of Personality & Social Psychology*, 78 (5). 837-852.

15. Kiesler, S. and Sproull, L. "Social" Human Computer Interaction. In Friedman, B. ed. *Human Values and the Design of Computer Technology*, CSLI Publications, Stanford, 1997, 191-199.

16. Klingspor, V., Demiris, J. and Kaiser, M. Human-Robot-Communication and Machine Learning. *Applied Artificial Intelligence Journa*l, 12 (7-8). 573-617.

17. Langlois, J.H., & Roggman, L.A. (1990). Attractive faces are only average. Psychological Science, 1, 115-121.

18. Langlois, J.H., Roggman, L.A., & Musselman, L. (1994). What is average and what is not average about attractive faces? *Psychological Science*, 5, 214-220.

19. Langlois Lab,University of Texas, Austin,USA.http://homepage.psy.utexas.edu/HomePage/Group/LangloisLAB/composites.html

20. Laurel, B. Interface Agents: Metaphors with Character. in Friedman, B. ed. *Human Values and the Design of Computer Technology*, CSLI Publications, Stanford, 1997, 207-219.

21. Moon, Y. When the Interface is the Face: Social Responses to Interactive Technologies. *Report* (113). 23-24.

22. Nass, C. and Steuer, J. Anthropomorphism, Agency, and Ethopoeia: Computers as Social Actors. *Human Communication Research*, 19 (4). 504-527.

23. Nass, C., Steuer, J. and Tauber, E., Computers are Social Actors. In *Proceedings of Human Factors in Computing Systems '94*, (1994), ACM Press: New York, 72-78.

24. Reichard,J. *Robots: Fact, Fiction, and Prediction*. Penguin Books, 1978.

25. Reilly, W.S.N., A Methodology for Building Believable Social Agents. In *Proceedings of Autonomous Agents '97*, (Marina Del Rey, California USA, 1997), 114-121.

26. Roy, N., Baltus, G., Fox, D., Gemperle, F., Goetz, J., Hirsch, T., Margaritis, D., Montemerlo, M., Pineau, J., Schulte, J. and Thrun, S. Towards Personal Service Robots for The Elderly. http://www.cs.cmu.ed/~nursebot/web/papers.html

27. Social Robots Project, Carnegie Mellon University, USA. http://www2/cs.cmu.edu/afs/cs/project/robocomp/social/www/SRPmain.html

28. Sproull, L., Subramani, M., Kiesler, S., Walker, J.H. and et al. When the interface is a face. *Human-Computer Interaction*, 11 (2). 97-124.

29. Takeuchi, A. and Nagao, K., Communicative Facial Displays as A New Conversational Modality. In *Proceedings of INTERCHI '93*, (Amsterdam, the Netherlands, 1993), ACM Press: New York, 187-193.

30. Takeuchi, A. and Naito, T., Situated Facial displays: Towards Social interaction. In *Proceedings of Human Factors in Computing Systems '95*, (1995), ACM Press: New York, 450-455.

31. Zebrowitz, L.A. *Reading faces: Window to the soul?* Westview Press, Boulder, CO, USA, 1997.