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A review of recent research in social robotics

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Research in social robotics has a different emphasis from research in robotics for factory, military, hospital, home (vacuuming), aerial (drone), space, and undersea applications. A social robot is one whose purpose is to serve a person in a caring interaction rather than to perform a mechanical task. Both because of its newness and because of its narrower psychological rather than technological emphasis, research in social robotics tends currently to be concentrated in a single journal and single annual conference. This review categorizes such a research into three areas: (1) Affect, Personality and Adaptation; (2) Sensing and Control for Action; and (3 Assistance to the Elderly and Handicapped. Current application is primarily for children's toys and devices to comfort the elderly and handicapped, as detailed in Section 'Toys and the market for social robots in general'.

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Introduction

The concept of a social robot appeared only recently, and is to be contrasted with many other subfields of robotics. Briefly, what are now called robots first appeared in the late 1940s in the form of multi-jointed mechanisms (arms and hands) that were controlled remotely by a human operator for the purpose of manipulating radioactive and other hazardous materials. A few years later digital computers were being developed, and it was obvious that by connecting a digital computer to such a mechanism one could program the computer to make the mechanism (now becoming a 'robot') preform programmed manipulations. These have included: factory robots for product assembly; space and undersea robots for scientific exploration; military robots for surveillance, handling unexploded bombs, and transporting equipment; home robots for vacuuming carpets, and surgical robots, among other applications. Various reviews of the history and emergent fields of robot research are available [1,2].

Broadly speaking, any robot that interacts with a human being may be termed a 'social robot', but this might include many human–robot collaborations where the intent is to perform given mechanical manipulation tasks continuously controlled in real-time (such as the DaVinci surgical robot), or intermittently reprogrammed by a person (space and undersea robots, some factory robots) in what is called 'supervisory control' [3]. Such human-machine combinations are now called 'cobots' (Figures 1, 2 and 3).

But 'social robot' has generally come to have a narrower meaning, namely where the robot's target function is not some external mechanical task, but is the human user itself. The robot's purpose is to engage in an affective or otherwise helpful interaction directly with the person. In the last few years a dedicated scientific journal (*International Journal of Social Robotics*) published by Springer has appeared. There is also an annual International Conference on Social Robotics. Robotics research that focuses on the social aspect in contrast to the mechanical or computer aspects is almost entirely directed to that journal and that conference. For those reasons, the great majority of the recent research reviewed below is from that those publications.

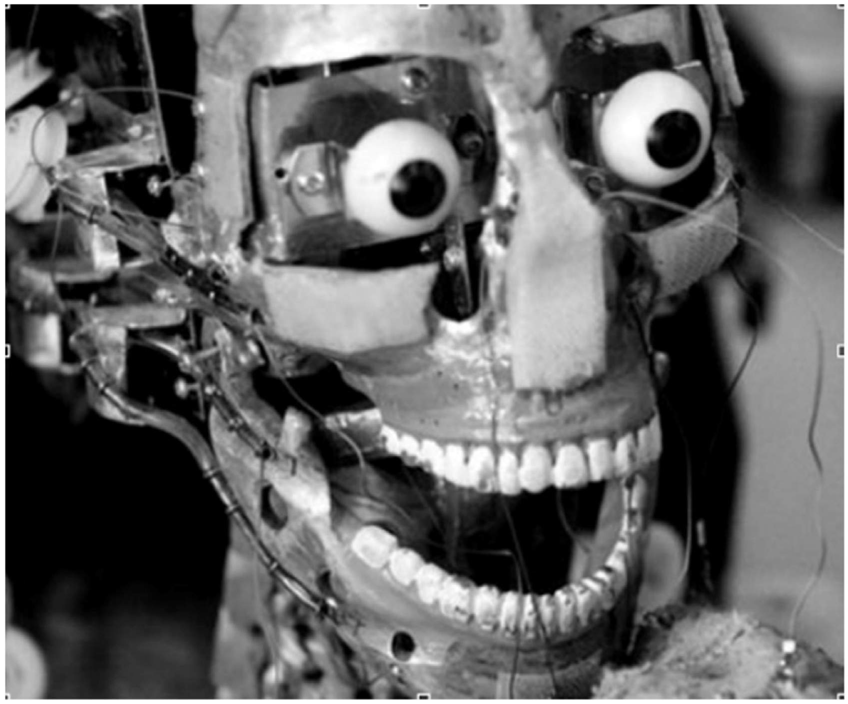
Research areas

Below I categorize the research as follows: (1) Affect, Personality, and Adaptation; (2) Sensing and Control for Action; (3 Assistance to the Elderly and Handicapped (though admittedly there is significant overlap, and the categories may not fit some papers. For completion, I add a fourth brief section called Toys and Markets. Presently the market is greatest for social robot toys, but the sophistication of psychological research embodied in many toy robots is currently shallow. Included are some photos of social robots.

Affect, personality, and adaptation

Adaptive research concerns using information about the user in order to adapt to the user's particular needs and performance intentions, thereby improving acceptance. Martins *et al.* [4•] provide a 2019 review of user-adaptive interaction focusing on non-physical interaction, including a taxonomy of lines of such research. They also propose a taxonomy to help future researchers classify progress and gaps in research, of which there remain many. Several investigators focus on how movements of the robot's body parts imitate human emotions:

Figure 1



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The MIT Media Lab (Cynthia Breazeal) robot face showing mechanisms for eyes and mouth with the skin removed.

Figure 2

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Social robot attracting attention of a senior user.

Figure 3

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Toy robot offers to check child's pulse.

Johnson and Cuijpers [5] claim to adjust the head position to express six different emotions: anger, disgust, fear, happiness sadness and surprise. Willense and VanErp [6] describe experiments resulting in the claim that robot-initiated touch of the user induces positive responses, even without prior bonding. Block and Kuchenbecker [7] evaluate human responses to different physical characteristics such as softness and warmth as well as hugging actions. Results show that users prefer soft, warm hugs to hard, cold hugs, and hugs that release immediately. Palanica *et al.* [8] examine whether verbal comprehension of questions differs with respect to whether the speaker is a human or a social robot, with no other gestures or head gaze. They find that for easy questions the comprehension from the robot speaker is significantly inferior to that of the human, but for more complex questions listener comprehension reaches parity between the robot and human speakers. The question of just what is anthropomorphism has intrigued various researchers: Ruijten *et al.* [9] discuss different interpretations of the concept and use a one-dimensional scale to map it, using the Rasch model, which measures latent traits like attitude or ability, based on the probability of an individual getting a correct response on a test item.

While the above studies evaluated characteristics of social robots based on physical attributes, a number of studies consider properties that might be considered cultural. Lupowski *et al.* [10] present an experiment on whether an inconsistent background context ('uncanny valley') of a social robot would influence differences in comfort level, human-likeness rating and emotional reaction. They find statistically significant differences in comfort levels. A study by Hoorn *et al.* [11] finds that most of 54 female participants in a 'speed dating' situation did not perceive a difference between in the 'emotional behavior' of an actual human versus a synthetic respondent. A framework for 'cultural competence' in the knowledge management of a social robot, based on Bayesian and other relevance storage mechanisms, is proffered by Bruno *et al.* [12].

The perception of mistreatment of a robot is assessed by Carlson *et al.* [13]. Using images of robot faces, Stroessner and Benitez [14] find a preference for contact with more human-like and especially feminine robots. Physical embodiment is preferred to virtual reality according to experiments by Wang *et al.* [15]. However, in a comparison between a VR and a physical robot, Shariati *et al.* [16] find the VR robot to be just as acceptable as the real one for therapy and educational purposes. Coghian *et al.* [17] examine strengths and weaknesses in whether kindness or cruelness to social robots makes us kinder or crueler to humans. Finally, deGraaf and Allouch [18] detail variables related to social robot acceptance.

Sensing and control for action

This section considers researches that focus more on the physical interaction of human and social robot. There are few books that cover the sensing and control for action as well as affective and ethical aspects of social robotics.

Korn [19•] has assembled an important collection of considerations and research results, and provides a good introduction to social robotics. While safety is essential to human–robot collaboration for industrial manipulation settings potentially involving collisions, it is important even in 'social' tasks such as applying makeup to the human face, as shown by Homma and Suzuki [20]. But in social robotics more attention has been given to the problem of motion planning, not only for collision avoidance but also for human-likeness (Wolherr and Turnwald [21]. Erlich and Cheng [22] use EEG potentials to evaluate whether robot movements are realistic, while Heimerdinger and LaViers [23] measure the relations between stylized gait and environment context on affect in motion perception. Kaushik and LaViers use low degree of freedom non-humanoid virtual characters to animate virtual robots from human capture data [24]. Predicting the target for human reaching is a basis for robot control for Hamandi *et al.* [25]. Velocity profile and orientation are the criterion for understanding robot motion in experiments by Papenmeier *et al.* [26]. Action recognition can also be accomplished by capturing from successive frames the skeleton model of the robot and the expectation of the pose (Liu *et al.* [27]).

In order to coexist with humans one problem for a robot is to understand what the human is doing. Kostavelis *et al.* [28•] utilize a dynamic Bayesian network to assess the capability of people with mild cognitive impairment in unconstrained environments. Their robot uses RGB optical and laser sensors to apprehend human activities and decompose them into connected behavioral units. The resulting Bayesian network model suggests an important avenue for discovering and modeling elements of social behavior. They deploy their robot in 12 real environments, and provide 61 references related to this approach. Kaushik and LaViers [29] demonstrate how to imitate human motion using a low degree-of-freedom robot. When the work space must be restricted there is a problem in teaching the robot to limit its movements, and Sprute *et al.* demonstrate how a tablet combined with virtual reality can be used to program 'virtual borders' in the workspace [30]. When human operator vision is occluded there are issues in robot-mediated collaborations, which Radmard *et al.* analyze [31]. Human–robot collaboration can require that the robot recognize different poses of the user's face (Yoon *et al.* [32]).

A self-driving car is a form of social robot, and can be said to possess the equivalent of eye-gaze behavior that reflects the car's intentions. Karatas *et al.* [33•] study how such artificial eye-gazing affects the human sense of inter-subjectivity. This is important because social behavior such as eye/head gaze and hand gestures are a poorly understood aspect of driving which is very difficult to replicate in self-driving cars. It appears to the author that this study suggests a line of research critical to understanding driving in general. Li *et al.* [34] show how a robot can improve grasping strategies by recognizing fragility, rigidity, and texture. Yamashita *et al.* [35] investigate the causal relation between robot touch sensation and its perceived personality. Spatola *et al.* [36] show that human attentional performance can be boosted by the presence of other agents (robots) as compared to the human working in isolation. Komatsubara *et al.* [37] develop a technique for estimating children's social status in classrooms by studying interactions with a social robot.

Assistance to the elderly and handicapped

This is one social robot application that has received much attention. For example, families coping with autism often struggle with social and emotional communication. Ismail *et al.* [38] review research on use of robots for children with autism, identifying as gaps: diversity in focus, bias in research toward specific behavior impairments, and effectiveness of human–robot interaction after impairment. Jouaita and Henaff [39] also review robot-based motor rehabilitation in autism, which they claim is a neglected area.

Alhaddad *et al.* [40] quantify significant harm levels of autistic children throwing small social robots to the head. A robot teleoperated by a caregiver is shown by Yoshikawa *et al.* [41] to enable subjects to disclose to the robot concerns that they had not previously disclosed to the caregiver. Parviainen *et al.* [42•] survey professional caregivers for the elderly, and find the caregivers accept robots for lifting objects to help the patients, but are reserved about tasks that involve touching the patient. Because caregiver perceptions are so critical to making social robots effective in real settings, this is a good start but one demanding much more research to get caregivers on board with social robots. Karunarathne *et al.* [43] ask the question 'Will older adults accept a humanoid robot as a walking partner?' and find that they prefer walking with the robot to walking alone. Moro *et al.* [44] investigate how the dynamic social features of robots such as facial expressions and gestures affect the interaction experience of cognitively impaired seniors, and find that such factors significantly increase levels of engagement. Portugal *et al.* [45] similarly study a mobile social robot interaction in an elderly care center, and provide feedback as to the usability, appearance, interaction and acceptance of the robot.

Use of a social robot to help persons with motor impairment is an established research area. Fattal *et al.* [46] describe use of a mobile robot to help people with quadriplegia to grab objects both within and out of their field of view. Zhang *et al.* [47] describe the architecture and design of a wearable robotic system for body posture monitoring, for correction and rehabilitation assist, and to relieve head, neck and back pain. Wang *et al.* [48] present a model-free incremental learning methodology and demonstrate its application to a single-leg exoskeleton.

Toys and the market for social robots in general

It is important, for user acceptance, for government regulator (medical, psychological) acceptance, and for sales appeal, that social psychological and human factors engineering/research be applied to social robots. This is especially true for children's toys since children are the most vulnerable of various user categories. Most sales of social robots are for children's toys. A Google search for 'social robot toys' brings up 93 million hits and provides the reader a cross section of social robot toys.

Three photos are also posted here: one showing the mechanism of the MIT Media Lab social robot face with the skin covering removed, one showing an older person, presumably impaired cognitively, attending to a robot face (screen), and one showing a child interacting with a toy robot.

The current global market social robots is small in contrast to that for robots for factory, military, hospital, home (vacuuming), aerial (drone), space, and undersea applications. A Global Social Market Review [49] estimates that the 2017 social robot market was 288 million dollars, and that it will rise to 700 million by 2023. Market considerations are analyzed by end use, geography, competition, and degree of robot intelligence. Leading companies are listed.

Conclusions

The field of social robotics research has emerged in only the last several years, in contrast to research on robots for physical manipulation, where the target is not service to a human user. Psychology is potentially the most relevant discipline for making robots socially acceptable, marketable, and effective for the varied target human needs. Social robotics research is diverse and growing at a rapid pace. Currently most sales are.

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CRediT authorship contribution statement

Thomas B Sheridan: Investigation.

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