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Artificial skin and tactile sensing for socially interactive robots: A review

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HIGHLIGHTS

- We present a review of tactile communication for socially interactive robots.
- Diverse approaches to touch sensing for socially interactive robots are discussed.
- An overview of data transmission and calibration methods is presented.
- Current work in touch interpretation for socially interactive robots is reviewed.

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ABSTRACT

During social interaction humans extract important information from tactile stimuli that enriches their understanding of the interaction. This process depends, however, not only on the underlying characteristics of touch, but is influenced by factors such as the context of the interaction, together with the cultures, beliefs and emotions of the individuals who are communicating. The development of a similar capacity in a robot – to "understand" the intended meaning of touch – has the potential to significantly improve the future success of intuitive human–robot interaction. This paper reviews the state-of-the-art in interactive touch and tactile sensing for socially interactive robots.

1. Introduction

For some time now there has been research directed towards building robots that can interact with humans [1,2]. A pioneering project involved developing the "whole arm manipulator", or "WAM" [3], a robotic arm that was able to sense contact along its whole length, and yield to pressure when it came into contact with obstacles (or humans). Since this early work, robotics research directed towards human–robot interaction (HRI) has fallen into two main areas: humanoid robotics [4–11], and devices typically described in the robotics literature as "robots for psychological enrichment" [12–26].

The fundamental premise of researchers who work in the field of humanoid robotics is that machines (robots) that are designed to operate in social spaces should have capabilities that are "human-like". The intent is to match robot attributes, such as size, strength and dexterity, to tools and structures in the human environment. It is often assumed – perhaps uncritically – that a person will be more psychologically comfortable with a human-like robot. Doubt is cast on this assumption, however, by Mori's theory of the "uncanny valley" [27]—the paradoxical feeling of strangeness when one views a human-like entity that is "not quite perfect".

Although early work in humanoid robotics involved the creation of robots that were, paradoxically, very machine-like in their rigid appearance and behaviour, there is growing awareness in the robotics community of the importance of aspects such as appearance, tactile feel and "social" behaviours of humanoid robots. There is evidence in the literature [28] that any mismatch between a person's expectation of a robot's appearance and behaviour, and the robot's actual appearance and behaviour is a potent source of negative feelings towards the robot. If a machine's appearance and behaviour closely resembles that of a human, our expectation is that it will exhibit human-like characteristics such as intelligence and emotion [29,30]. Mori's theory of the uncanny valley [27], extended by Ishiguro [31], predicts that there is a point where the lack of "something" produces a negative familiarity that results in dislike and rejection (Fig. 1). It is, after all, practically impossible to

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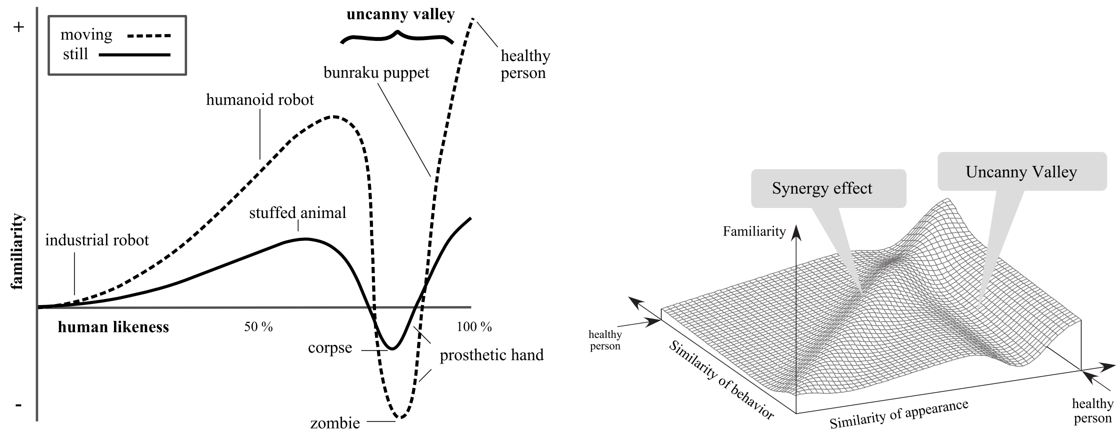

(a) Mori's uncanny valley.

(b) Ishiguro's extended uncanny valley.

Fig. 1. The uncanny valley according to Mori (a) and to Ishiguro (b).
Source: From [27,31] respectively.

make a replica of a human, and the consequent mismatch between expected and actual behaviour will often raise feelings of repulsion and disapproval.

Roboticists and social researchers are also beginning to appreciate the importance of social, emotional and ethical issues raised by the development of humanoid robots. For example, recently there has been provocative work on social and moral relationships [32–34]; mental models and shared grounds [35]; emotional interaction [36]; the concept of "personal space" [37]; and long-term social interaction [38,39] between a human and a robot. Other work has been focused on human-like appearance and behaviours through the construction of "androids" [31,40] – humanoid robots with a very human-like appearance and more human-like movement – and "geminoids" [41]—androids that could function as a duplicate of an existing person.

Robotic devices aimed at "psychological enrichment" usually take the form of an animal, doll, or pet, such as Paro the robotic seal [12,19,21,23], the Haptic Creature [17,20,26,42], CHARLIE [24], or Huggable the teddy bear [16,18]. These devices aim to first recognise some aspect of a human user's mental state by measuring how they handle the device, and then to respond in some physical way. There is also interesting related work on The Hug [13], a cushion-like form that mediates physical interaction between people in different locations.

As interactions between humans and robots become more complex, there is increasing interest in building robots that can interact with humans in more intuitive and meaningful ways [43]; robots such as the Fish–Bird wheelchairs [44], Robota the humanoid doll [15], KASPAR [22,25,45], and Paro the robotic seal [12,46] have demonstrated that people naturally seek interaction through touch and expect even inanimate-looking robots to respond to tactile stimulation. In robotics, it is therefore important to design a method for touch identification that can be active over all or most of the robot's surface area; this could be achieved using an artificial "sensitive skin".

The functional requirements of an artificial sensitive skin remain debatable and are, to some extent, dependent on the application that the skin is intended for. In the literature, an artificial sensitive skin[1] is usually considered to be a flexible [47,48], stretchable [49] array of sensors that fits onto curved robot surfaces of substantial extent. It may have the ability to sense tactile information such as pressure [50], texture [51], and temperature [52]. In some cases, multiple layers of heterogeneous sensors are used in an attempt to more closely imitate the capabilities of human skin [53,54]. Additionally, soft and silicone-based materials have been used to cover the sensors, to improve wettability and friction properties [55], to increase the contact area, and to give a more "pleasant" feel [12,31,52,56].

The interpretation of touch in robotics and, in particular, via a sensitive skin is a vast, unresolved research area that will play a crucial role in the further development of human–robot interaction (HRI). A robot that is able to "feel", "understand" and respond to touch in accord with human expectations could lead to more meaningful and intuitive HRI. In previous publications we have seen reviews in the area of human–robot interaction [2], socially interactive robots [1], tactile sensing for robotics [57], and tactile human–robot interaction [58]. This article extends those works by focusing particularly on tactile sensing, artificial skin and tactile interaction in socially interactive robots.

In the absence of extensive work in robotic touch the design of touch sensors and, in particular, a robotics sensitive skin is generally guided by a broad knowledge of how information is acquired, encoded and transmitted at various stages of the human sense of touch. In this vein, Section 2 begins with an introduction to the human sense of touch. Section 3 then presents an overview of human-based tactile communication. A review of the state-of-the-art on tactile sensing and artificial sensitive skin for socially interactive robots is introduced in Section 4. Touch interpretation in social human–robot interaction is reviewed in Section 5, followed by a brief discussion and conclusions in Section 6.

2. The human sense of touch

The skin is the largest of all human organs [59]. It gives us the sense of touch, the first sense to develop *in utero* and (arguably) the most important of all human senses [60,61]. Our bodies are literally covered by a huge network of touch receptors and processing centres – the somatosensory system – that allow the perception of temperature changes, pain and irritation, kinaesthesia,[2] touch and vibration; our muscles, joints and organs are all connected to nerves that constantly send information to the brain.

The somatosensory system comprises two different subsystems: cutaneous and kinaesthetic [62,63]. The cutaneous subsystem involves physical contact with the outer surface of the body

[1] The terms "artificial sensitive skin", "artificial skin", "sensitive skin", and "robotics skin" will be used interchangeably when referring to an artificial sensitive skin for robotics applications.

[2] The sense of muscular effort that accompanies a voluntary motion of the body.

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