Where Robots and Virtual Agents Meet

A Survey of Social Interaction Research across Milgram’s Reality-Virtuality Continuum

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Abstract Traditionally, social interaction research has concentrated on either fully virtually embodied agents (e.g. embodied conversational agents) or fully physically embodied agents (e.g. robots). For some time, however, both areas have started augmenting their agents’ capabilities for social interaction using ubiquitous and intelligent environments.

We are placing different agent systems for social interaction along Milgram’s Reality-Virtuality Continuum—according to the degree they are embodied in a physical, virtual or mixed reality environment—and show systems that follow the next logical step in this progression, namely social interaction in the middle of Milgram’s continuum, that is, agents richly embodied in the physical and virtual world.

This paper surveys the field of social interaction research with embodied agents with a particular view towards their embodiment forms and highlights some of the advantages and issues associated with the very recent field of social interaction with mixed reality agents.

Keywords Social interaction · Mixed reality agents · Human-robot interaction · Human-computer interaction

1 Introduction

In today’s digital society, an ever-growing amount of human activities relies on digital technology. Trends such as inexpensive internet access and the diffusion of wireless computing devices have made ubiquitous or pervasive computing a practical reality that augments the normal physical environment and supports the delivery of services to human users anytime and anywhere. A lot of interfaces for these environments are built on the idea that a social interface, that is, an interface availing of human-like social cues and communication modalities, is the most natural and thus most effective way for humans to interact. This belief is rooted in the assumption that humans react socially to computers [56] and has been the driving force behind a big body of research in the areas of Human-Computer Interaction (HCI) and Human-Robot Interaction (HRI).

But while in the past software agents and robots have usually been seen as distinct artefacts of their respective domains, the modern conception is, in fact, to consider them as particular instances of the same notion of agent—an autonomous entity capable of reactive and pro-active behaviour in the environment it inhabits. From this point of view, the concept of embodiment, intended as the structural coupling between an agent and its environment (e.g. [68]), provides the common ground upon which different strands of agent-related research can be analysed and compared.

Indeed, by placing social interaction research on Milgram’s Reality-Virtuality Continuum [43] (see Fig. 1), ac-
According to the nature and extent of their embodiment in a physical or virtual environment, we can view robots and virtual agents as embodied at the extremes of the continuum.

These extremes are the areas where most of the traditional social interaction research to date has taken place, and where we first turn our focus, giving a brief overview of the commonalities and differences of traditional HCI and HRI research in Sect. 2.

However, as Sect. 3 details, both the virtual and robotic domain have started moving away from the edges for quite some time now by embodying their agents in ubiquitous environments, that is, environments that are “augmented” with digital sensors and devices. This shift has occurred with two main objectives in mind. On the one hand, the ubiquitous environment is supposed to augment the agent’s interaction capabilities, feeding it information about the user’s whereabouts and state to assist social interaction. On the other hand, the agent provides the user with a social interface that acts as a representative of the services the intelligent environment offers.

Following social interaction research from both sides away from the edges and further along Milgram’s continuum naturally leads us to the very centre of the spectrum, where social agents are endowed with mixed reality bodies and placed into mixed reality environments. Only very recently have researchers started to look at this area, as Sect. 4 will show, but they have already identified some unique possibilities and challenges for social interaction.

2 Social Interaction with Robotic and Virtual Agents—Research at the Extremes of Milgram’s Continuum

When investigating human-agent social interaction (see Fig. 2 for examples of real and virtual social agents), both HRI and HCI share many similarities, as they can both draw on insights into human social research.

Fong et al. (2003) use the term “socially interactive robots” to describe robots for which social interaction plays a key role. For Fong et al. these robots are important in domains where robots must exhibit social interaction skills, either because such skills are required for solving specific tasks, e.g. as in scenarios where robots are envisioned working shoulder to shoulder with humans [1], or because the primary function of the robot is to interact socially with people, e.g. as in companion [16] and educational robots [59].

The specific origin of a robot’s social skills, such as their role within the robot’s cognitive apparatus, remains an open issue which usually also depends on the particular research emphasis, i.e. if in pursuance of a robot-centred or a human-centred perspective [17].

However, there is enough evidence to suggest that these robots need to exhibit a certain degree of social intelligence, for the way they manifest their awareness and react to the presence of humans, in order to be accepted as social peers [47], or simply tolerated within humanly populated environments [53].

Similar issues are being investigated within the 3D and virtual reality communities, as a large body of works now shares an interest in the incorporation of virtual characters into virtual and augmented reality environments. Human-like virtual characters (virtual humans) are being used with success as virtual representatives of human users in virtual conference applications [61], or as fully autonomous agents inhabiting virtual worlds to enhance the user’s experience and ease his interaction with the virtual world. Such characters can make the interaction more engaging and make the user pay more attention but they can also require more effort to interact with the system, e.g. in educational and training applications [11]. A much appreciated feature in the latter type of applications is that virtual humans can provide pedagogical assistance that can be tailored to the needs and preferences of the learner [7].

Studies focusing on how the appearance of virtual characters can affect cooperation, change attitudes, and motivate users [57, 67] indicate that humans treat them as social partners and, in particular, that many of the rules that apply to human-human interaction carry over to human-agent interaction.

The result is that, despite technical and methodological differences between dealing with robotic and virtual domains, today a large number of issues behind the construction of successful social agents cross the boundaries of agent species.

What distinguishes all the research in socially intelligent agents is the emphasis given to the role of the human as a social interaction partner of artificial agents and, subsequently, to the relevance attributed to aspects of human-style social intelligence in informing and shaping such interactions. The consensus in social agent research is that effective human-agent interaction greatly leverages the instauration of a human-style social relationship between human and agent.

Dautenhahn’s model of social intelligence [15] in human societies is characterised by the ability of recognising each