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What is a Social Robot?

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Abstract. This paper discusses the concept of a *social robot*. Developing from recent work on physical embodiment, the necessity for a *socially embodied* robot is presented. Current work via the *Social Robot Architecture* seeks to develop and demonstrate these concepts.

1 Introduction

As cognitive science too often neglects the question of physical embodiment, it similarly has neglected the concept of embodiment in a social environment. As indicated by [Edm97], it is argued that "social intelligence is not merely intelligence plus interaction, but should allow for individual relationships to develop between agents". Our research deals with a collective of homogeneous robots with relatively limited functionality and the development and implementation of a social structure between these robots. We present the *Social Robot Architecture*, which integrates the key elements of *agenthood* and robotics in a coherent and systematic manner.

Section 2 and section 3 respectively offer an introduction to the concept of embodiment and sociality. Agent-based robotics is presented in section 4, while section 5 discusses the concept of a *social robot* and the development of the *Social Robot Architecture*, with discussion and conclusions presented in section 6.

2 Embodiment

While some treat the body as peripheral and tangential to intelligence, others argue that embodiment and intelligence are inextricably linked. Experience building robots has led Brooks to argue that embodiment is vital to the development of artificial intelligence [Bro86] [Ste94]. Brooks advocates the behaviourist approach to combat the difficulty in developing purely internal symbolic representational models of reality utilised in classical AI approaches.

Johnson, Lakoff, et al. argue that our ability to understand and reason abstractly relies heavily on our bodily experience and therefore that "high level" intelligence depends crucially on embodiment, [Lak87], [LJ80]. Based on the argument of movement, manipulation and perception involving the use of recurring patterns, this promotes the concept of linking embodiment to intelligence. Phenomenologists also argue against the use of internal symbolic representations or mental states saying that *"an embodied agent can dwell in the world in such a way as to avoid the ... task of formalising everything"* because its *"body enables [it] to by-pass this formal analysis*"

[Dre79]. Dreyfus also says that when people have 'mental considerations', they "do so against a background of involved activity" [Dre91].

While some believe that implementing a control paradigm on a physical robot is sufficient for fulfilling the embodiment criteria, Dautenhahn and Christaller [DC95] argue that this results in a robot not being aware of whether it is acting in a simulated or physical body. They write *that "the development of a conception of the body, which is generally discussed as the acquisition of a* body image *or* body schema, *is necessary for embodied action and cognition*". They continue in proposing that the use of "evolvable" robots with an adaptation of both body and control mechanisms to its environment could provide an ideal solution.

Our robots are not alone in their world; therefore, in order to achieve an *embodied robot*, we seek to address the question of both its physical and social presence in the real world.

3 The Question of Being Social

Sociality implies the existence of interactive relationships. An agent capable of interactive, communicative behaviour is considered social. The simple existence of two autonomous robots in the same environment forces aspects of social contact, be it direct or indirect.

One perspective is that one should be aware of their mental states (i.e. motives, beliefs, desires, and intentions) and be able to attribute mental states to others, which allows one to predict and analyse the behaviours of both oneself and others. This would allow one to be able to deal with both highly complex social relationships and also exhibit the ability to deal with abstract problem solving. The *social intelligence hypothesis* or *Machiavellian intelligence hypothesis* (recent discussion in [KDG97]) claims that all these intellectual capacities evolved out of a social domain, i.e. out of interactions with social embodied individuals. The *social intelligence hypothesis* promotes the theory that in order to achieve a degree of intelligent behaviour from an agent, the agent must be both embodied in a physical environment and embodied in a social environment. This agent will therefore be subject to complex dynamic social interactions in a real world, which is believed by [DC95] as being necessary for the development of an artificially intelligent agent.

A mutual understanding between members of a social group is required for the establishment and continuance of the group. Problems arise when single members are motivated exclusively by self interest. The question of individual safety is only ensured when a strict and fixed hierarchy exists like in a 'super-organism' structure (strict hierarchy), i.e. social insects, with anonymous contact between its group members. But in most social groups degrees of flexibility are found with each member's social status evolving and may be different in differing "goal oriented contexts". While non-human primate societies generally use physical contact for 'social grooming'

with the use of its body and behaviour for communication, man has developed a more effective means via highly elaborated language.

It is believed that language does not only function to acquire knowledge about behavioural characteristics of others, but also to find out the internal states of others (i.e. their feelings, attitudes, etc). In order to build up a basis for interaction and co-operation, individuals have to communicate and merge their conceptions of the world (i.e. world models), with the degrees of abstraction being socially grounded and continuously updated.

4 Agents and Robots

Fukuda *et al* conducted research in the early stages of robot agents on both multi-robot systems in DARS (Distributed Autonomous Robotic System) [CF+95] and reconfigurable robots within CEBOT (Cellular Robotic System) [Fuk+89]. Arkin and Balch [AB98] developed their reactive strategy for multi-agent co-operation with robots searching for trash objects, which they grasp and carry to wastebaskets. Balch *et al* investigates the impact of communication in reactive multi-agent robotic systems in [BA94].

Simulation work has also been undertaken in [VHA96], [Edm98] via social embeddedness and agent development, [JC97] concerned with the inherently social aspects of multiple agent systems and the development of a framework for characterising social decision making, [CV97] with the virtual society COMRIS, [CRF+97] with personality-based multi-agent co-operation, and [SM98] with the generation of a multi-robot controller with a group of mobile robots performing a clean-up and collection task.

Dautenhahn and Billard have undertaken work on "social robotics" where the emergence of a social behaviour is achieved through the interaction of the two robots via a simple imitative strategy in their Heugellandschaft experiments [BD97]. Dautenhahn explores the interest of social interactions through the imitation mechanism. She addresses problems such as social intelligence, communication and body image. While interesting from an artificial life perspective, Dautenhahn does not utilise an explicit communication protocol or architecture that directly supports formal social interaction. The "social" behaviours produced are primarily emergent and based on semaphore communication. Similar research by Pfeifer [Pfe98] demonstrates where very simple robotic entities exhibited *emergent* social behaviour.

5 The Truly Social Robot

We introduce here the term *social robots*. It is our conjecture that a distinction exists between *societal robotics* and *social robotics*. The former represents the integration of robotic entities into the human environment or society, while the latter deals specifically with the social empowerment of robots permitting opportunistic goal solution with fellow agents.

While the term "socially intelligent agents" has been used in the context of human-robot interaction via research in, for example, service robotics [WPA97], we believe that this represents an example of *societal robotics* where robots are introduced into society with degrees of required functionality to act as aides to people.

We propose the term *social robotics* as a more generic representation for multi-robot interaction, which encompasses collaboration, communication, co-operation, co-ordination, communities, identity, and relationships, with reactive and pro-active behavioural models. Social robots constitute:

> *A physical entity embodied in a complex, dynamic, and social environment sufficiently empowered to behave in a manner conducive to its own goals and those of its community*

Our research deals with the following key elements in the pursuit of the *social robot*:

- Physical: Physical robots embodied in the physical environment
- Reflexive: Fast reactive / reflexive nature to unforeseen or unanticipated events
- Deliberative: Computational machinery required in order to realise defined complex goals
- Social: The ability of the robot to interact with other robots in order to achieve these goals

Towards realising a truly social robot, we have developed the *Social Robot Architecture* [DCO+99] [ROD+99] [ODC+99] in order to directly address the key issues mentioned above.

5.1 The Social Robot Architecture

We now describe the *Social Robot Architecture*, which goes some way toward achieving team building and collaborative behaviour through the judicious synthesis of the reactive model with that of the deliberative model. The architecture *(figure 1)* is comprised of four discrete layers: physical, reactive, deliberative, and social.

Physical: Robots in terms of this research may take the form of either that of a physical entity, specifically the Nomad Scout II or a simulated entity.

Reactive: A series of fundamental reflex behaviours are implemented at this level. The sensory information is processed resulting in clear *agent_events* and communicated to the deliberative level. *Agent-commands* are received from the deliberative layer.

Deliberative: This comprises of a Belief-Desire-Intention (BDI) architecture developed through Agent Factory [Col96] [OCC+98]. The perception process deals with *converting agent events* into beliefs and adding them to the belief set providing the agent with an up to date model of its current perceived situation and results in the agents' commitments being updated accordingly. Pre-existing commitments are analysed and those pertaining to the current time frame honoured resulting in either a communicative act being sent to the social level or a physical act being passed to the actuators via the reactive level.

Social: Our agents interact via an Agent Communication Language (ACL), called Teanga[1] [ROD+99] which is based upon Speech Act Theory [Aus69].

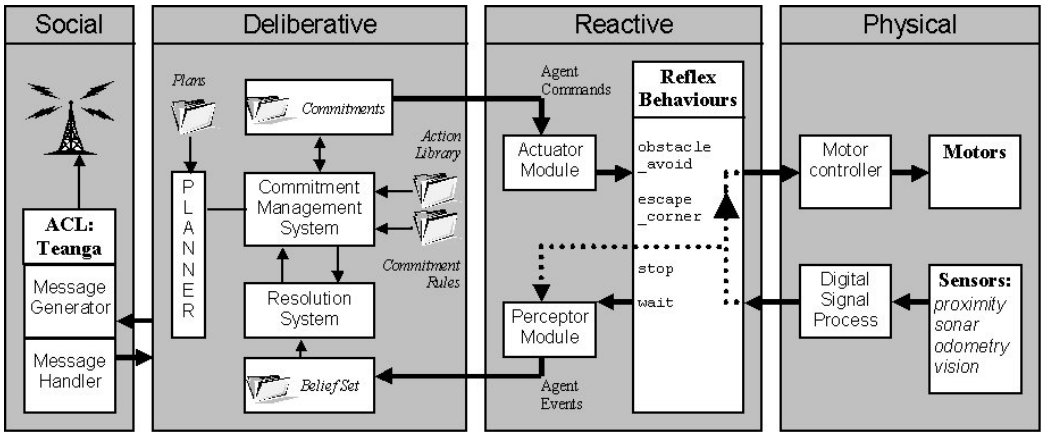

Figure 1: The Social Robot Achitecture: The Robot Agent

The *Social Robot Architecture* facilitates the development of teams of robots which may be heterogeneous, both in terms of behaviour and hardware. Behavioural heterogeneity is achieved through the use of Agent Factory to develop BDI agents with differing capabilities, e.g. commitment adoption strategies, knowledge resources, planning facilities, etc.

The use of a standard interface between the deliberative component and the reactive layer (i.e. the agent-events and commands) means that robots with different sensors and actuators can be readily integrated into the system. The use of a standard interface for interaction, i.e. the ACL Teanga, allows these heterogeneous agents to communicate and co-ordinate.

6 Discussion and Conclusions

This research has discussed *Social Robots* and an accompanying *Social Robot Architecture.* The *Social Robot Architecture* offers a modular control architecture that integrates separable layers into a coherent whole. To date, experimental evidence has demonstrated that *constructive* and *coherent* collaboration is achievable in restricted task domains via the "Waltz experiment" [DCO+99] [ROD+99]. We are confident that our social robot architecture is scalable and ongoing research seeks to demonstrate its applicability to different real-world problem domains.

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[1] Teanga is Irish for "language" and interestingly is an anagram for a agent

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