Social Interaction between Robots, Avatars & Humans

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Abstract—**With the recent development of the field of social robotics and in particular the need to negotiate explicit social interaction and behaviour between both socially capable robots and between robots and humans, this work presents the development of a framework which supports coherent social interaction between real and artificial systems. The Social Robot Architecture is implemented in conjunction with the Virtual Robotic Workbench, a cohesive framework which integrates physical robots, virtual robot avatars and humans in a shared social space.**

I. Introduction

With the development of the field of social robot research in recent years, a strong need has developed for a coherent development frameworks for heterogeneous robots that supports explicit social interaction between robots (whether real or virtual) and between robots and humans. In situating this work in the current state of the art in the field, it is important to highlight that there are generally two camps of social robot research aimed at developing deliberative pro-active social capabilities.

The first involves the development of explicit control architectures for (ideally) heterogeneous robots with the capacity to communicate, coordinate, and engage in social complex *inter-robot* behaviours. The social interaction design strategy is primarily based on a bottom-up approach where the social capabilities are often additional communication mechanisms implemented on robotic devices. There are numerous "levels" of sophistication from simple message passing through, for example, light-based transmitters and receivers [1] and more recently [2], to more sophisticated Belief-Desire-Intention-based social control paradigms as found in the Social Robot Architecture [3][4].

The second approach to social robot research involves empowering a robot with the social functionality required to engage human participants in some form of directed social engagement. Such systems often involve building robotic devices with a degree of anthropomorphic representation (head, body, facial expressions, hand gestures, etc) (see [5] for a discussion). The control systems generally employ key human-centric interaction modalities such as speech and even models of emotion in order to realise as natural a social interaction as possible.

While the original motivations for both camps may be different, they are not mutually exclusive. Core to both perspectives is the necessity to structure each system's social environmental information. In the case of one robot encountering another whether explicitly or not, the structuring of one robot's perceptions of the other intuitively promotes employing some form of social mechanisms. When this extends to explicit communication with a view to collaborating, this need is fundamental. This work seeks to bridge these two camps.

The following section provides a state of the art perspective and helps ground the work presented in the subsequent sections in the context of current research.

II. Background

The field of social robotics aims to strongly situate the participants in a real, physical environment where mechanisms are employed to achieve a degree of coordinated action between two socially capable entities. A review of social robots [6] outlines recent advances in the state of the art of robots engaging in some form of social interaction, whether explicit or emergent. While work on stigmergent behaviour between a collective of robots [7][8][9][10][11] has resulted in some interesting social outcomes, it is, by its embodied emergent nature, inherently difficult to design explicit complex social tasks using such a strategy. A similar minimalist approach is adopted by Donald & Jennings [12].

A number of more deliberative architectures have employed degrees of social capabilities such as ALLIANCE [13], and the MICROB projects [14] but pro-active communication remains limited. The STEAM architecture [15] offers a more sophisticated social infrastructure where a formal language of communication is employed but it has limitations in its ability to deal with adaptive capabilities.

Two strategies for single robot control include the Social Robot Project [16] and MINERVA [17], which incorporate explicit social features for human-robot interaction. Kuniyoshi [18] demonstrates an alternate approach through the development of social mechanisms of attention with cooperation achieved through observation and imitation without explicit communication.

To date, human-machine interaction, whether in the form of a virtual avatar or a physical robot, has primarily centred on either the real or the virtual domain, but rarely both (a notable exception being the Agent Chameleons project [19]). While the work presented in this paper is fundamentally grounded in the physical world, the objective has been to achieve coherent social interaction in an artificial system in real-world environments, whether through robot-robot, robot-avatar (using augmented reality), or robot-human social interaction. We have therefore developed the Social Robot Architecture (SRA) [3] and it's associated Virtual Robotic Workbench [20] [21].

III. The Social Machine

We argue that explicit social support mechanisms are necessary in order to work toward true interoperability and cooperation between omnipresent heterogeneous robots and effective human-robot interaction. Such mechanisms need to ease configuration and networking difficulties for large scale heterogeneous robotic teams thus enabling dynamic composition of sensors (distributed sensing) and actuators, and subsequently support dynamic discovery of resources and peers. They should also offer a framework for social skills implemented in a re-usable and standardised form.

The Social Robot Architecture implements the embodied social features of artificial identity, stereotype, character, roles and task decomposition [5], with the Virtual Robotic Workbench providing a mixed real and virtual environment for agent-based autonomous mobile robots. The Virtual Robotic Workbench dismantles the traditional perceived divisions between physical robots, simulation, real world environments and virtual reality. Key to this framework is the ease of integration of these four perspectives with the strong integration of social mechanisms that facilitate cooperation between people, robots and virtual avatars.

Core to realising the social machine are an underlying social robotic architecture, a notion of robot identity, together with an instrument for visualisation of social robotic experiments. We now consider each of these in turn.

A. The Social Robot Architecture

The *Social Robotic Architecture* [3][22] is a design methodology based upon the combination of BDI (Belief, Desire and Intention) agents, a reactive behavioural system, and an explicit social infrastructure (figure 1). Key components of the architecture are:

- A hardware abstraction layer for heterogeneous robot platform applications utilising an abstract interface to the Physical Layer (actuation and perception).
- A coherent reactive-deliberative control synthesis based on confidence building mechanisms employed for robust sensor fusion. Complex behaviours embrace methods for real time mobile robot obstacle avoidance similar to the Vector Field Histogram Plus [VFH+] [23] and the Dynamic Window algorithm [24].
- A Belief-Desire-Intention Deliberative Level developed through Agent Factory [25], is implemented with several agents supervising the different functional levels of the robot. These agents vary in complexity from simple procedural knowledge modules that deal with lower level capabilities of the platform (i.e. sensorial organization, configuration and behavioural arbitration), to means-ends reasoning.
- A FIPA (http://www.fipa.org) compliant social level to support explicit social interaction by employing speech acts [26] (such as requesting, ordering, informing or promising) which sends a message to one or more socially capable acquaintances in order to affect their mental states. In this work, the robotic agents interact via the Agent Communication Language (ACL) *Teanga* described in [27].

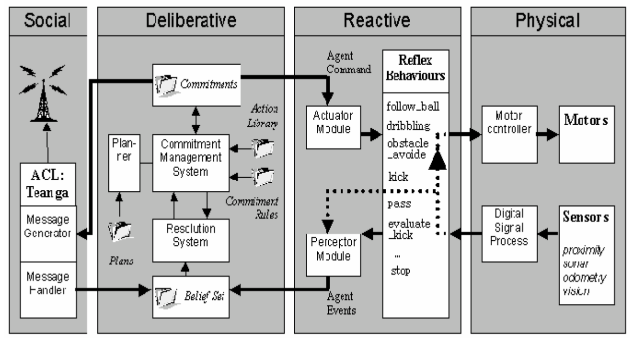

Fig. 1: The Social Robot Architecture [3].

This constitutes a fundamental component in bridging theoretical reasoning processes and the physical environment from the perspective of a stronger interpretation of embodiment as discussed in [5].

B. Robot Identity

Robot identity is defined as *"that which differentiates a robot system from any other and preserves its distinction from its environment regardless if it has any observable influence on, or actuation with, its environment"* [3]. The following paragraphs briefly outline the social mechanisms employed to achieve the social transparency required for heterogeneous multi-entity explicit social interaction. See [5] for a detailed explanation of the social mechanisms implemented within this paper. It should be noted that these mechanisms are fundamentally geared towards the social empowerment of artificial systems and the inclusion of the human in the loop is grounded on a machine-based perspective.

In this work, robot *identity* involves the development of explicit models of a robot's own attributes and also social models of other robots it encounters. This includes the complete set of its internal and external attributes, which can develop over time as the system learns and adapts to its environment (figure 2).

Character is viewed as the *perceived* identity by one entity of another. It is defined here as the combination of perceived features or qualities that distinguishes one entity from another in that entity's social envelope. It is a subset of the set of internal and external attributes found in the identity superset and also develops over time as one system learns more about another. The character, or perceived identity, of one system is grounded on a fundamental set of internal and external attributes that describe that robot, here dealt with through the use of stereotypes.

Stereotypes constitute a set of key attributes, both internal and external which define the functional capabilities of a system. It is a basic mechanism employed in social task decomposition, where subtasks are allocated based on a key functionality set of each system to bootstrap the task decomposition and allocation problem in collaborative work.

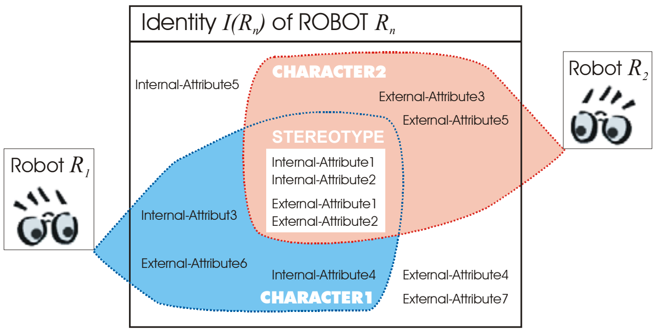

Fig. 2: A defined subset of internal and external attributes constitutes the stereotype that robot R_n is associated with.

While the fields of human-robot, robot-robot, and avatar-robot social interaction have been researched largely independently of each other with limited transference of strategies, this work embraces the notion of artificial identity within the context of all three. The Virtual Robotic Workbench, as detailed in the following section, provides a framework which facilitates the integration of all three domains: Robotics, people, and virtual robot avatars. The specifics of how the concepts of identity, stereotypes, and character are also illustrated in the following section.

C. *Virtual Robotic Workbench*

In order to illustrate the seamless integration of human, robot and avatars in a social collective, we employ the Virtual Robotic Workbench [20][21], a software framework built upon seminal works conducted by the Collaborative Virtual Environment (CVE) and the Distributed Interactive System (DIS) communities. The central ideas of the Workbench are the immersion of robots and human operators in a shared collaborative environment and the adoption of mature Multi Agent Systems (MAS) technology. The benefits of data diffusion and sharing techniques (i.e. based on multi-casting) for multi-agent-systems have been recently recognized (i.e. in [28]). The Shared Environment paradigm embraces every aspect of our work from data communication to visualization tools. Each activity is seen as a collaborative experience in which information about activities (i.e. telemetry/ sensor data) and interaction between all participants (i.e. robots, experimenters and environment) are collected and shared to various degrees within the framework in a manner mimicking the diffusion of real events through normal sensorial apparatus. In our solution the connectivity to the shared environment is embedded in the sensing and actuating stratus of our robotic agents. By altering the robot embodiment and fitting an interface to a standardised software agent layer in the architecture, the Virtual Robotic Workbench allows the investigation of a new set of possibilities for interaction and interoperability in robotic contexts. These include indirect communication through augmented sensing, cooperation based on standard protocols (i.e. Contract Net, Auction) and migration or mutation of mobile agents among different robotic platforms. The Virtual Robotic Workbench offers:

– A communication medium - based upon a XML multicast protocol, which is exploited for dynamic resource discovery and to exchange information and control among humans and robots.
– A visualisation medium which offers real-time, multimedia visualisation facilitating behavioural scrutiny and situational awareness for humans involved in tasks such as semi-autonomous remote control, supervision and inspection of large teams of autonomous mobile robots.
– A FIPA compliant Agent technology supervising the social interface between each user and the shared environment and personal assistants embedded in the human user interface.

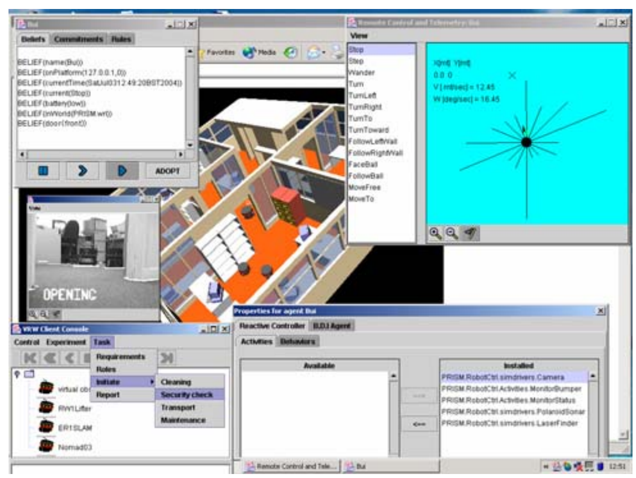

Fig. 3: Workbench Applet GUI (from upper left clockwise: BDI debug window, telemetry and tele-robotic panel, BDI property dialogue, Workbench console with task/role management and acquaintance list, RTP video feedback, 3D view in background).

In designing the Workbench infrastructure, the main guiding principles were portability and simplicity of use. We were also driven by the desire to permit lightweight nodes embedded within Java Applets in order to facilitate distribution over the Internet. Figure 3, for instance, shows an example of combination of graphic user interface (GUI) components delivered to an Internet client in a Java Applet. For the same purpose, the Workbench messaging system follows an abstract, spontaneous networking paradigm that allows fast configuration and the use of a mixture of transport-layer protocols. The Workbench defines an application layer protocol consisting of two distinct services:

– A *Directory Service* used to transmit an index of the overall data available in the Workbench. This service may also be used to transmit low-rate telemetry information (e.g. positional updates) to low-bandwidth devices.

– A *Media Service,* distributing audio, video and fast-rate telemetry and sensorial data to media-enabled and high-bandwidth devices. The present implementation is based upon the Java Media Framework (JMF) (html://java.sun.com) and the Real Time Protocol.

The main component of the VRW data, together with an index of all supplementary multimedia sources, is encapsulated in a proprietary XML format (figure 4) in order to account for different data types and flow rates (for a detailed account see [21]). Figure 4 also shows how the VRW XML packet may contain a URLS which is used to publish static attributes. When a URLS tag is encountered for the first time, the receiver node launches a background thread to read from the URLS. The content is then parsed and included in the reader's knowledge base. In this manner, a node connecting to the workbench is gradually informed about the entities participating in the action without the need for more complex session-oriented protocols.


```
<VRW source=ER1Slam port="4445" time=2002121513308734>
  <URLS>
    <Model>http://draco.ucd.ie/models/scout.wrl</Model>
    <Rtp_video_stream>192.1.132.2/9002/1</rtp_video_stream>
    <Stereotype>
      http://draco.ucd.ie/stereotypes/SLAMrobot
    </Stereotype>
  </URLS>
  <scene_address>Eurokom.RoomA</scene_address>
  <telemetry>
    <odometry time=2002121513308734>
      <X>233</X ><Y>0</Y>
      <Z>0</Z><Alpha>0</Alpha><V>98,50</V>
    </odometry>
    <sensor
      type=RANGE_SONAR time=2002121513308722 unit=inch>
      <resolution>22.5</resolution>
      <data>55 25 34 36 46 67 255 25 64 72 40 29 34 63 45 33</data>
    </sensor>
    <sensor type=RANGE_LASER time=2002121513298443 unit=cm>
      <resolution>0.5</resolution>
      <geometry>0 0.5 180</geometry>
      <data>2550 2550 1454 1561 1460 120 120 118 110 72…</data>
    </sensor>
  </telemetry>
</VRW>
```


Fig. 4: Virtual Robotic Workbench data broadcast in XML format.

In figure 4 the published URLS (in bold) contains links to the three-dimensional model of the robot (i.e. used to represent the robot as an avatar in virtual or augmented space), the address of the RTP session used to broadcast the video acquired from the onboard camera and the link to the robot stereotype. The latter constitutes a *stereotype* system (as discussed in section III.C), which is used to bootstrap acquaintance modelling and to speed the verification of agent capabilities during group formation and task assignment. The present implementation is based upon a shared ontology referred by the ACL messages of the participant agents (see FIPA specifications: http://www.fipa.org). The ontology describes concept related to robot capabilities in form of AF-APL beliefs rules like:

```
BELIEF(has(device(Camera)))&
BELIEF(has(algorithm(face-detection)))
   => BELIEF(can(detect(human)))
```

We are currently working in translating such definitions with a more standardised tool for ontology representation (i.e. Protégé [http://protege.stanford.edu]) and the incorporation of an automated ontology parser within Agent Factory. Capabilities ontology for the definition of stereotype, task requisite and role specification can be accessed and edited through the Workbench as shown in figure 4.

The following section instantiates these concepts in experiments with a collective of social robots, avatars and humans which demonstrate its flexibility and usability.

IV. Implementation / Demonstration

A collective of Nomad Scout II robots manufactured by Nomad Technologies (http://nomadic.sourceforge.net), ER1 robots from Evolution Robotics (http://www.evolution.com), and two custom humanoid robots ("Anthropos" and "Joe") were employed for these demonstrations. For each sensor and actuator driver for each platform, we developed a simulated counterpart. These components enabled the VRW to handle the instantiation of mixed (physical-simulated) entities and collaboration sharing the same event space. Furthermore, we have developed augmented sensors modules which base the perception of simulated robots upon real sensorial data transmitted by real robots through the Workbench using distributed sensing strategies.

A key advantage of such augmented reality features is the ability to test real robotic agents in partially simulated scenarios. We can, for example, place robots in standard environments (i.e. mazes) and test them with simulated robots or other virtual elements added to their sensorial space.

In order to monitor these mixed reality scenarios we realised an augmented reality application enabling the visualization of virtual components through a Head Mounted Display (HMD). As in [29] our application defines a framework for shared tracking with multiple observers (HMDs and fixed mounted cameras). The present implementation bases tracking and visualization upon the Augmented Reality Toolkit [30] while the VRW Telemetry Service is exploited for the dissemination of observations and the dynamic discovery of peer observers.

Each instance of this application tracks cubic markers placed on top of each real robot (see figures 7b & 8), together with additional markers opportunistically located in the experimental environment. Each observation produces camera coordinates which locate the observer relative to the observed markers. Combining local and remote observations allows us to produce an observation graph which augments the visualisation capabilities of each observer. By sharing observation details, each observer can construct their own version of the observation graph. Such graphs increase the probability of being able to deduce the coordinates of simulated robots (i.e. finding a path in the observation graph) in the absence of the necessary direct observation. In order to exercise all the layers of our architecture together with these augmented sensing modules and visualization, we devised an exemplary task demonstrating basic inter-robot cooperation.

A. *Robot Waltz*

In this task – named *Waltz* - two robotic agents reproduce a dance while avoiding obstacles and arbitrate the dance steps through ACL directives.

```
// Make space for the dance
BELIEF(start) => COMMIT(Self,Now,ActivateBehavior(Step(maxDistance,120)))
// Stop in position ready to dance
BELIEF(toofar) => COMMIT(Self,Now,ActivateBehavior(Stop))
// start the dance as soon the follower is activated and joins the experiment
BELIEF(acquiantance(Follower)) & BELIEF(current(Stop)) =>
    COMMIT(Self,Now,adoptBelief(BELIEF(dancestep)))
// starts and requests a forward movement
BELIEF(dancestep) & !BELIEF(current(TurnRight)) =>
    SEQUENCE(
    COMMIT(Self,Now,ActivateBehavior(TurnRight))
          COMMIT(Self,Now,request(Follower,Turn)))
// starts and requests a forward movement after a turn
BELIEF(informed_belief(turned,Follower)) =>
    SEQUENCE(
    COMMIT(Self,Now,request(Follower,Step))
          COMMIT(Self,Now,adoptBelief(BELIEF(dancestep))))
// Interrupts forward movement in case of obstacle danger
BELIEF(acquiantance(Follower)) & BELIEF(danger) & BELIEF(current(Step)) =>
    COMMIT(Self,Now,adoptBelief(BELIEF(dancestep)))
BELIEF(acquiantance(Follower)) & BELIEF(informed(danger)) &
BELIEF(current(Step)) =>
    COMMIT(Self,Now,adoptBelief(BELIEF(dancestep)))
```

Fig. 5:

Fig. 6: AF-APL script for the leader-role in the Waltz task.

```
BELIEF(requested_achieve(Step,?X)) =>
        COMMIT(Self,Now,ActivateBehavior(Step(timeout,1500)))
BELIEF(danger) => COMMIT(Self,Now,inform(Leader,danger))
BELIEF(requested_achieve(Turn,Leader)) =>
COMMIT(Self,Now,ActivateBehavior(TurnRight))
BELIEF(turned) => COMMIT(Self,Now,inform(Leader,turned))
```

Fig. 7: AF-APL script for the follower-role in the Waltz task

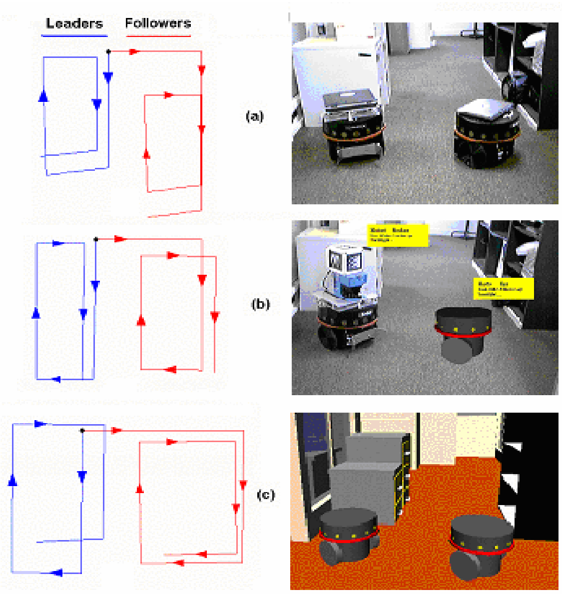

Fig. 8: Trajectory traces (left) and pictures (right) for few steps of the Waltz task. From top to bottom: (a) Full real experiment, (b) Real leader and simulated follower, (c) fully simulation dance.

Each dance step consists of a 90º degree turn and a forward movement. The robotic agent undertaking the leader *role* requests the start of every new step and the interruption of the current movement in the presence of any obstacles obstructing his or his partner's movement. The second agent, in contrast follows a simpler logic, executing every leader's order and informing him about any danger of collision that might occur during forward movements. Such *roles* may interchange between robotic dancers. Figure 5 and 6 contains segments of the AF-APL scripts governing such behaviours. Figure 7 shows trajectory traces logged by the VRW telemetry service together with the correspondent photos taken from the real scene, the HMD observing the mixed experiment from the VRW 3D visualization client.

Within the Mixed-Reality Waltz, the simulated robot receives scans (multi-casted through the VRW) from the real robot onboard laser of the real robot and converts these through a coordinate transformation (based on its known orientation to the real robot) to its own coordinate's frames. In this way we re-use the real sensor data to give obstacle detection capabilities to simulated entities. To an experimenter (observer) immersed in the shared tracking environment it appears like the simulated robot is avoiding real obstacles.

B. *Anthropomorphic Interfaces*

The Social Robot Architecture was also implemented on the humanoid robot "Joe" in order to demonstrate directed voice-based human-robot interaction. The VRW Augmented Reality capabilities permit a robot to know the position of a human participant and consequently to situate their behaviour, for example, facing the observer (when conversing) and passing the ball toward them (when playing soccer [31]).

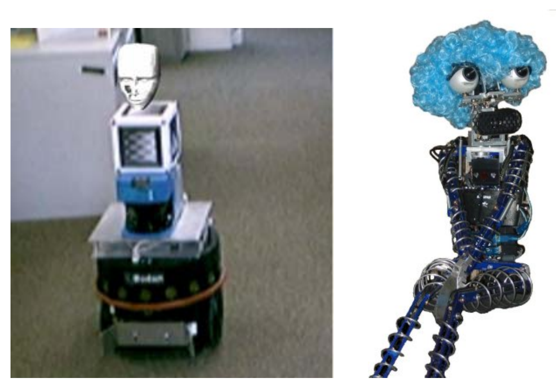

Fig. 9: Anthropomorphic interface with Nomad Scout II for robot soccer, and JoeRobot for conversation-based interaction

The ViaVoice (IBM) speech system was used for conversation based communication in conjunction with the Agent Communication Language: *Teanga* (as similarly implemented in work by Jacobus and Duffy [32]). The utterance types, based on Teanga's speech acts, consist of `query`, `inform`, `commit`, and `declare`, and their subtypes, with shorter versions of commonly used subtypes being optional. These combined to deliver the content, which consisted of an action type, a property, or an action modified by additional `properties`. These `properties` describe the state of the variable or object they are mapped to, and can be required parts of action types or expressed independently as an assertion of belief. Example speech acts include:

```
REQUEST   target:Joe, action:list_files,
          property:aloud
```

```
REPLY     target:human-user, property:[filelist]
REQUEST   target:Joe, action:open_file,
            property:[filename]
REPLY     target:human-user, property:[filename]
```

The avatar resident upon the robot also facilitates coherent identity perception for platform migration. Agents often migrate, undertaking differing embodied forms. Within such scenarios, consistent visual identity cues are fundamental (see related work [5]). A close relationship exists between the embodied form, and robotic identity as discussed in section III.

V. Conclusion

The development of complex socially capable artificial robots is gathering momentum. As such systems becoming more and more embedded in our physical and social environment, their integration into our social interaction space necessitate mechanisms which manage these new social contexts.

Within this paper, the combination of the *Social Robot Architecture* and the *Virtual Robotic Workbench*, provide a mechanism by which to accommodate such artefact interactions. This flexible framework for social multi-reality prototyping extends the social space of any one system to include a myriad of combinations of real and virtual interaction and cooperation. The objective has been to develop a flexible framework for social modelling on the part of the artificial system of whatever socially capable entity it encounters in conjunction with those mechanisms required to opportunistically engage its social partners. Experiments to date have verified the applicability and flexibility of this architecture. Future work will extend the human-robot social modelling infrastructure through the implementation of more powerful conversational mechanisms and interface paradigms such as found in affective social interaction work.

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