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Human-robot interactions: Social micro-abilities to establish and manage social exchange

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14. ABSTRACT
This project studied social abilities for establishing and managing social exchange in the 100-200 millisecond timescale, which we call social moments. These very fast micro-abilities underpin effective fluent interactions between human teams and are conjectured to be necessary for effective robot-human teams when fast interaction in close proximity is required. The first year of the project involved the development of a tele-robot system using small mobile robots and the design of cooperative and competitive team tasks that require social micro-abilities to establish and manage social exchange. The robots were designed to isolate the possible movements for conveying spatial intentions and awareness by constraining communication abilities to motion alone. The second year of the project involved the design of a set of robot micro-abilities to enable a robot to first interpret the motion of other vehicles during these tasks and then to intentionally convey its own state using the knowledge it gained. Empirical studies were designed to examine robot-robot, human-robot and human-human interaction. Together, this suite of experiments provides a methodology for practical study of the efficacy of different robot micro-abilities for signaling state and intentions. Ethical clearance was received later than anticipated in the project, and the third year of the project focused on conducting empirical studies to test human-human interactions though the tele-operated robots. These studies are the first to use human social micro-abilities as a model for robot micro-behaviors, to design empirical studies to systematically study social moments and their relevance to human-robot teams, and to develop principles and algorithms for social micro-abilities that enable robots to engage in effective social interactions.

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Final Report for AOARD Grant FA2386-14-1-0017

"**Human-robot interactions: Social micro-abilities to establish and manage social exchange**"

Report for 30th September 2017

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Abstract:
This project studied social abilities for establishing and managing social exchange in the 100-200 millisecond timescale, which we call *social moments*. These very fast micro-abilities underpin effective fluent interactions between human teams and are conjectured to be necessary for effective robot-human teams when fast interaction in close proximity is required. The first year of the project involved the development of a tele-robot system using small mobile robots and the design of cooperative and competitive team tasks that require social micro-abilities to establish and manage social exchange. The robots were designed to isolate the possible movements for conveying spatial intentions and awareness by constraining communication abilities to motion alone. The second year of the project involved the design of a set of robot micro-abilities to enable a robot to first interpret the motion of other vehicles during these tasks and then to intentionally convey its own state using the knowledge it gained. Empirical studies were designed to examine robot-robot, human-robot and human-human interaction. Together, this suite of experiments provides a methodology for practical study of the efficacy of different robot micro-abilities for signaling state and intentions. Ethical clearance was received later than anticipated in the project, and the third year of the project focused on conducting empirical studies to test human-human interactions though the tele-operated robots. These studies are the first to use human social micro-abilities as a model for robot micro-behaviors, to design empirical studies to systematically study social moments and their relevance to human-robot teams, and to develop principles and algorithms for social micro-abilities that enable robots to engage in effective social interactions.

Introduction:
For robots to develop social skills, they need to engage in interaction dynamics that have social meanings. Such interaction dynamics occur between social agents at multiple time scales. For example, small delays can indicate the state of a responder as eager or reluctant to engage with an agent. Movement patterns play a similar role in autonomous tasks. These interaction dynamics are called *social moments* (100-200 msec) to differentiate them from *cognitive moments* (on the order of 1-2 seconds) which utilize memory and other higher order cognitive skills. The problem for a robot is not just to coordinate its movement in close proximity to other agents without injury to the agent or itself, but for the robot (or their designers) to recognize that interaction dynamics at the 100 msec timescale can have social meanings. Just as words acquire social meanings that are continually updating, so also actions can indicate relationships such as safety, trust, cooperation or competition.

The challenge for designing social robots is where to start with social micro-abilities: it is not yet known what social moments are important to human-robot communication, nor what micro-abilities are needed by robots for participation in sensitive spatial tasks. Robots that reactively avoid obstacles have been used for decades, and current robots have sophisticated planning abilities. What is needed beyond such abilities is an understanding of how agents' actions contribute to relationship building and how inappropriate actions can erode them.

The overall goal of the project is to develop principles and algorithms for social micro-abilities that enable robots to engage in effective social interactions.

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Significance: Robots are moving into unstructured human environments which require them increasingly to be in close proximity to humans. For robots to move in the peripersonal space of other agents and humans, they will need the skills utilized in social interactions, signaling their own intentions and reading the intentions of others. Humans can read such signals at temporal scales below the level of conscious awareness based on movements that have social meanings. Studies of human social micro-abilities and the development of a toolkit of robot social micro-abilities lay the foundations for the development of relationships such as safety, trust, and cooperation with autonomous agents.

Experiment:

Robots: The robots in these studies were iRats [1], rat-sized mobile robots designed for research at the intersection of neurorobotics, neuroscience and embodied cognition. They have equivalent computational power to a PC on wheels, but with the advantage of a small size. For navigation tasks, this enables design and control of the robots' environment, while still benefitting from essential aspects of real-world robotics (rather than simulations).

Experimental system (see Figure 1): Humans operate iRats through tele-robotics and interact with autonomous or human-controlled iRats. Heterogeneous teams were set navigation tasks in constrained spaces, requiring joint actions and negotiation to resolve impasses and problems. Studies involved the recording and cataloging of movement and communication, which included observing movement from a distance and movement within each agent's personal space, robot orientations, and response times to movement. Evaluation was assessed through by humans as they interacted through tele-robots and through the time taken to complete team tasks.

Analyses (see Figures 2 and 3): Two different styles of analysis were designed and developed for these studies: traditional experimental methods, and also ethnographic – which are also called rich "thick" observations. Pilot studies used a 3x3x2 design (see Figure 2) systematically varying the knowledge of each robot, the task to be performed, and the degree of control given to the participants. Pilot studies showed that degree of control was useful for qualitative but not quantitative studies, due to the high range of variation in control abilities of the participants. Hence, full studies with human participants used a 3x3 design, focussing on the systematic variation of knowledge and task. A range of visualisation and analysis techniques were developed for revealing detailed patterns of interaction between participants, including quiver graphs (see Figure 3a), matrix plots of distance vs time for all conditions (see Figure 3b), phase plots of distances and velocities (not shown here). Software methods for all analyses were developed to enable rapid analysis of data.

Results, and Discussion:

A theoretical paper outlining the framework of social moments was published in 2017 "Social moments: a perspective on interaction for social robotics" [2]. The paper presents the neural basis for human comprehension of social moments and reviews current literature related to social moments and social micro-abilities. It discusses the requirements for social micro-abilities, how these abilities can enable more natural social robots, and how to address the engineering challenges associated with social moments.

Ethics: UQ BSSERC approval number 2014000830; Department of the Air Force: FOS20140022H
Ethical approval for the studies was received early in the project from the University of Queensland HREC, but took considerably longer from AFOSR. Once received, the focus was on completing the planned empirical studies.

The empirical studies with humans tele-operating the iRats was completed in the third year of the study and has been submitted for publication "Towards social micro-abilities for robots: Task signaling from tele-operated robot motion" [3]. In addition to the analysis techniques shown in Figures 1-3, multiple regression analysis was used to calculate significant variations in robot motions associated with the context of each trial. The analysis showed how pairs of participants created and evolved strategies to perform the task. Individual analysis of participant pairs showed a systematic precession of signals in the most reliable pairs in the cooperative tasks; and the effects of even slight asymmetries in the iRats in the competitive tasks. The studies demonstrated how motion of tele-operated real robots can be used as the communication medium (with no additional communication channels), grounded in the task, study environment and cultural norms of the participants. See [3] for further details.

This project has provided empirical and analytic methodology for deriving social micro-abilities from motion of robots engaged in cooperative and competitive tasks. A paper is in preparation describing how these methods support a toolkit for evolving micro-abilities for robot social signals, grounded in robot abilities and comprehensible to human interlocutors. Many human actions cannot be replicated by robots, due to their robotic form, limited speed of perception or action, or safety constraints in proximity to people. In these studies, human social interaction was constrained through teleoperated robots. This ensured that the robots were able to express the social signals required to complete the tasks, despite their non-human forms, and that the humans were able to interpret the signals.

Uniqueness/Impact (e.g. why is this research novel, different from what others are doing?
Previous approaches to social interactions with robots have assumed that social abilities build on cognitive skills (seconds to minutes). The approach pioneered in this project studies much faster time scales, studying "social moments" that take around 100-200 msec. The new approach involved investigation of a scaffold of social micro-abilities, starting from development of a system for studying human interaction dynamics.

List of Publications and any Significant Collaborations that resulted from your AOARD supported project: In standard format showing authors, title, journal, issue, pages, and date, for each category list the following:

a) papers published in peer-reviewed journals,
   Durantin, G., Heath, S. and Wiles, J. (2017) Social moments: a perspective on interaction for social robots. Frontiers in Robotics and AI, volume 4, article 24 (6 pages), June 2017. Open Access.
b) papers published in peer-reviewed conference proceedings,
   n/a
c) papers published in non-peer-reviewed journals and conference proceedings,
   n/a
d) conference presentations without papers,
   Workshops on social robotics were hosted at the University of Queensland March 3-4, 2016; and May 5, 2017.

e) manuscripts submitted but not yet published
   A manuscript "Towards social micro-abilities for robots: task related social signaling from teleoperated robot motion" describes the empirical studies and is currently under review.
   A manuscript describing providing how these methods support a toolkit for evolving micro-abilities for robot social signals, grounded in robot abilities and comprehensible to human interlocuters is under development.

f) provide a list any interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.

- The grant prompted a visit by PI Wiles to AFRL at Wright Patterson Air Force Base in Dayton OH in June 2016, funded by the Windows on Science program. The visit was hosted by Dr Nandini Iyer, and involved a research seminar to a broad audience, as well as a series of topic-specific meetings with researchers from several labs. Of particular interest was the study of interaction dynamics in teams and the use of automated techniques such as the Discursis conversation analysis tool (Discursis.com) developed by Prof Wiles and her team. The WPAFB visit was followed by a reciprocal visit from Dr Iyer to Prof Wiles' research team at the University of Queensland. Dr Iyer gave a seminar to a broad group of communication researchers across engineering and humanities, and met individually with specific groups. She also brought transcripts of conversations between servicemen communicating in noisy environments and she worked with the Discursis development team to study the interaction dynamics between interlocutors under different levels and patterns of noise. A follow up meeting between the researchers is planned for 2017.

- The WPAFB visit and Ben Knott's annual grant meetings also facilitated collaboration with Dr Greg Funke from WPAFB.
- A significant collaboration has been established with Dr Andrea Chiba at UCSD and Dr Greg Funke to develop advanced analysis methods to understand the interaction dynamics in human-robot teams using open data sets from the fields of human-robot interactions and social neuroscience, and to develop robots that function as cooperative team members. A joint USAF(US)-DSTG (Australia) project has been awarded to develop this collaboration.
- A student exchange between Dr Chiba's lab at UCSD and Prof Wiles' lab at UQ took place in 2017, funded by a new AFOSR student exchange scheme.

Reference

1. Ball, D., Heath, S., Wyeth, G.F., Wiles, J. (2010) iRat: Intelligent Rat Animat Technology, Proceedings of the *2010 Australasian Conference on Robotics and Automation (ACRA),* Brisbane, Australia.
2. Durantin, G., Heath, S. and Wiles, J. (2017) Social moments: a perspective on interaction for social robots. Frontiers in Robotics and AI, volume 4, article 24 (6 pages), June 2017. Open Access.
3. Heath, S., Durantin, G., and Wiles, J. "Towards social micro-abilities for robots: task related social signaling from teleoperated robot motion" (under review).

Attachments:
Power point slides containing Figures 1-3.

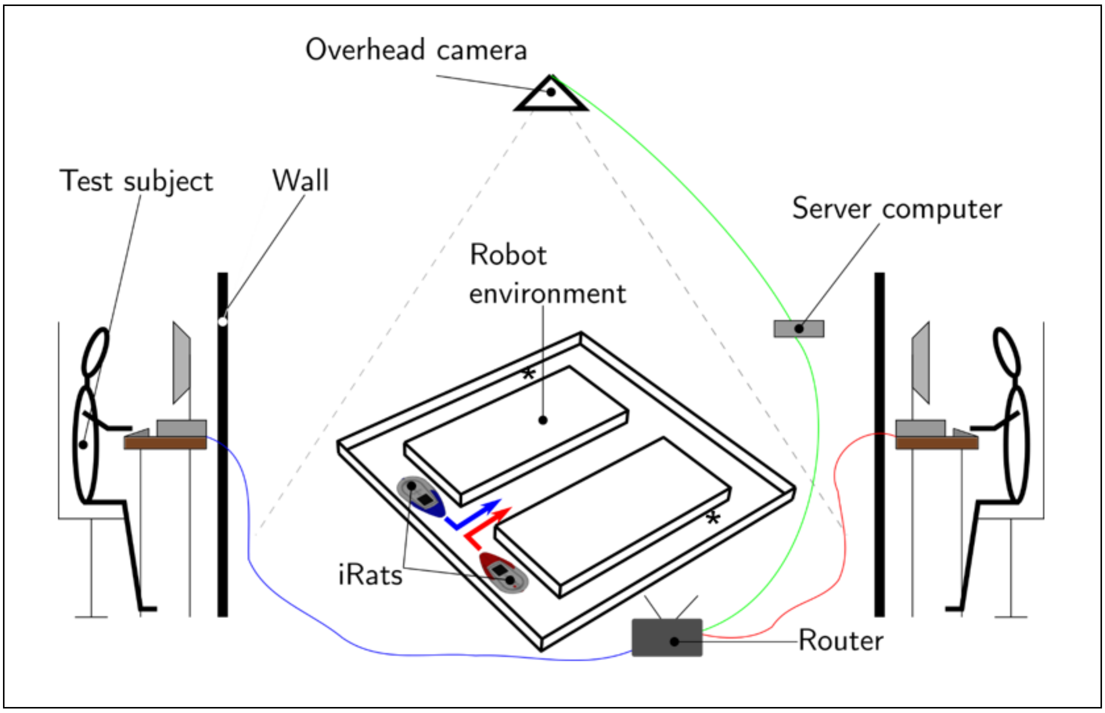

Figure 1. Experimental system.

- Two robots (iRats) are controlled by two people around a simple figure-of-8 maze in opposite directions. The drivers can use the arrow keys on the keyboard to control the iRats, or the space bar to use their "horn".
- At the intersections, the robot drivers are forced to make a decision between letting the other

robot pass through first, attempting to beat the other robot, or using the horn. The interactions will be recorded using an overhead camera for the robots, and a keyboard logger for the horn and movements.

- The system hardware consists of three PCs, an overhead camera, a router and the two iRats. Connecting the system using ethernet and WiFi to a single router allows all the devices to see each other on a single network.
- The three PCs and the two iRats all run Ubuntu linux. Software for controlling and tracking the iRats is re-used, while a graphical user interface for the robots was developed.
- The two people are within different rooms in the same building, using lab PCs that are connected by wires to the router with a delay of approximately 0.5ms between the two PCs when using the horn (the horn goes direct from one person to the other, and not to the robot). The iRats are wirelessly connected to the same router, causing a delay of approximately 25ms when processing a driving command.
- The system uses Robot Operating System (ROS), a communications layer for robots. ROS acts as the backend for the telerobot system, allowing capturing images from the iRats and overhead camera, and processing both driving commands and the horn.
- The system uses a browser based frontend, using Chrome to display the video feeds and provide the driving interfaces. Libraries used in the frontend include `roslibjs` (for communications) and `d3` (for displaying graphics).

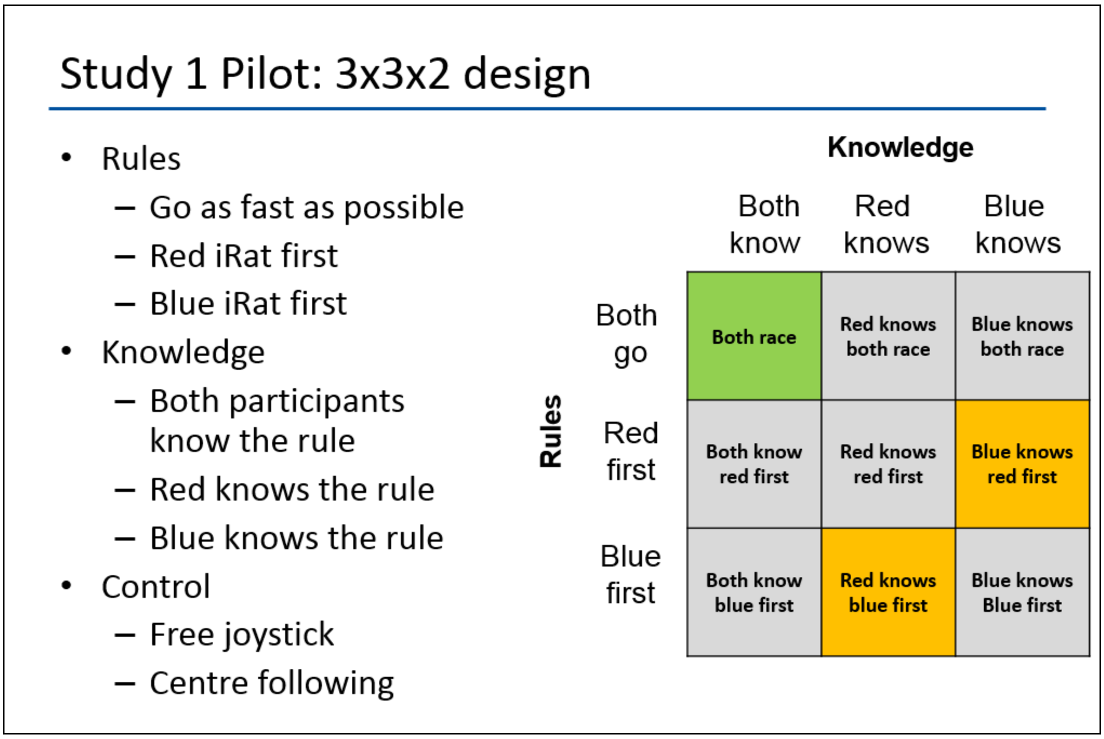

Figure 2. Experimental design. The pilot design was 3x3x2 (3 rules that define the task for the robots; 3 states of knowledge about those rules; 2 levels of control). The full study used only the centre-following joystick control due to the high variability with the free joystick condition.

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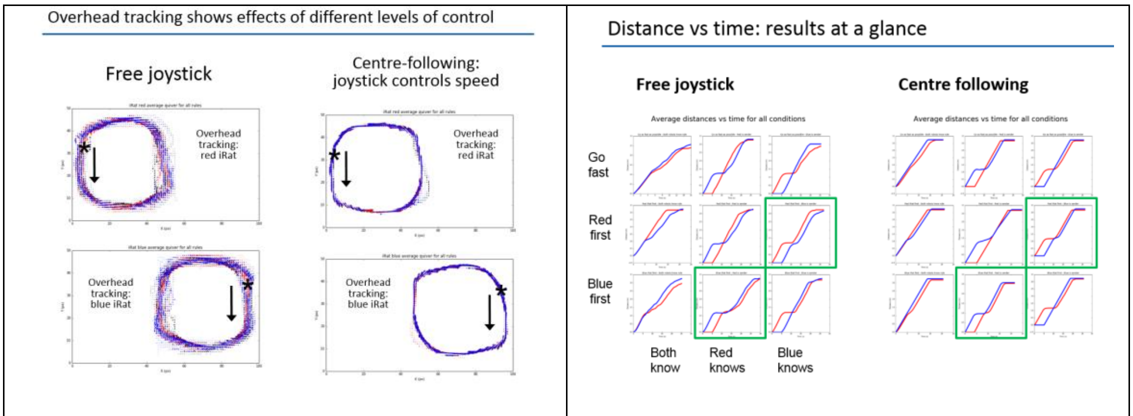

Fig 3a. Quiver graphs.

Fig 3b. Matrix of line plots.

Figure 3. Visualizations of performance illustrating some of the analysis methods that were used for fine-grained analysis of micro-abilities. Like a radiography image, it takes time to learn to read each visualization technique, but once learned, they provide detailed insight into individual and group behavior on a task. Quiver graphs (Fig 3a above left) show the variation in spatial position for each participant over multiples trials. They are useful for revealing the range of variation exhibited in different conditions and different levels of control. Note the spatial variation in the free joystick condition (left) is much higher than the more controlled center-following condition (right). Study participants have fewer options for signaling intention in the more constrained condition. This limits expressivity but resulted in faster convergence on stable interpretation between participants. Matrices of line plots (Fig 3b above right) showing the distance travelled by each robot vs time were used to show all 18 conditions (3x3x2) at a glance. Characteristic behaviors can be compared across all conditions at a glance.

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