Human - Robot Complementarity
Learning each other and collaborating

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As robot capabilities increase, the complexity of controlling and manipulating them becomes complex and cumbersome making intuitive Human-Robot Interaction all the more necessary for seamless human-robot collaboration. In this paper, we look into the ability of collaborators to understand each other’s intentions and act accordingly in order to promote the collaboration. We focus on scenarios that human intentions are communicated through movement. In order to endow robots with understanding of human intentions, as well as with robot behaviours that humans interpret correctly, we need to look at mechanisms humans recruit to perceive and communicate intentions. We then need to distil the essence of these mechanisms so that they can be applied to completely non-anthropomorphic robot collaborators.

Additional Key Words and Phrases: Human-Robot Collaboration, Human intentions, Robot intentions, Assistive teleoperation

1 MOTIVATION

Intuitive Human-Robot Interaction is necessary to allow human-robot collaboration in a seamless way. While the capabilities of robots increase, the complexity of controlling and manipulating them becomes complex and cumbersome. This is further stressed out in cases where the user is impaired and must be relieved from extreme physical or cognitive load.

Essential for achieving intuitive and seamless human-robot collaboration is the ability of both human and robot to be able to understand each other’s intentions and act accordingly in order to promote the collaboration. In this paper we present our research plan for developing methods that will endow robots with this understanding, allow robots to behave in ways that humans interpret correctly, and enable shared control between a robot and a user to achieve a goal.

We are interested in applications where the medium of interaction is human movement, which guides the robot’s actions either explicitly (e.g., assistive teleoperation) or implicitly (e.g., shared-workspace collaboration). To guarantee seamless human-robot collaboration three high-level requirements must be satisfied:

1. Communicate to humans the intentions of robots
2. Communicate to robots the intentions of humans
3. Shared control that weighs intention of both sides, decides about the appropriate action and does not disrupt human or robot behaviour.

To that end, it is of great interest to explore how a human and a robot can collaborate to learn a task in the first place. In other words, how do we prompt human motor learning (and thus performance) by involving the robot in the process and how do we manipulate robot learning to take advantage of human expertise? Such a co-training gives the

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human and the robot an understanding of each other's intentions and behaviour that would be extremely difficult to communicate otherwise.

2 BACKGROUND

2.1 Communicating robot intentions to humans

Humans could understand a robot's intention by predicting its behaviour or even by using their own motor system to understand intention in case of anthropomorphic robots. While interacting with a robot, a human is expected to build an internal representation of the robot movement behaviour in a similar way the brain retains internal models of own body (Wolpert and Ghahramani 2000), external objects (Cerminara et al. 2009) and the world in general (Berkes et al. 2011). These internal representations allow prediction of own movements, movements of external objects, etc.

An interesting observation is that the control of anthropomorphic and non-anthropomorphic robots differ, possibly because (in case of anthropomorphic robots) the user controls the robot as if it was their own body (Oztop et al. 2015). It seems that in this scenario humans could recruit processes similar to those used in social interactions. In social interactions humans can predict other people's actions and intentions by observing among other things their movements (Frith and Frith 2006). Wolpert et al. (2003) have suggested that we use our motor system to understand actions and that this is an efficient mechanism for making inferences in social interactions. Internal modelling processes have been proposed to be linked with mirror neurons during cognitive processes, like human interactions and understanding intention of other (Miall 2003).

2.2 Communicating human intentions to robots

Translating human intention to appropriate signals for the robot could be perhaps a more complicated process. Research relevant to communicating intention in physical interactions (Strabala et al. 2012) could be used as a starting point for reading human intention in human-robot interactions. In certain applications, like *robotic assistive therapy*, movement intention could be provided by a brain-computer interface (Wairagkar et al. 2016).

We are mostly interested in exploring how human intention can be modelled in scenarios where the human is controlling the robot via a medium like a joystick. To the best of our knowledge there are no recent papers discussing this issue. In an older study (Horiguchi et al. 2000), the authors explored naturalistic human-robot collaboration based upon mixed-initiative interactions in a teleoperating environment.

2.3 Shared control and collaboration

Throughout literature there are several interesting directions and challenges that one can take to build shared-control systems that promote collaboration.

A first question is how can we manipulate behaviour to facilitate intention inference? While humans can use motor prediction and understand action intention to interact with robots, robots can be built to further facilitate that the inference of intention unambiguously resolves to the correct robot goals. Movements are usually planned based on cost functions related to shortest distance, minimum energy consumption etc. An interesting idea is to modify robot motion planning so that it explicitly prompts human inferences about robot's expected action (Dragan et al. 2013). According to Dragan et al. (2013) motion planning in collaborative agents must be based in eligibility rather than predictability to allow 'intention reading' at an early stage of robot's motion execution. The authors argue that robots must be eligible in all collaboration scenarios, including shared-workspace collaboration, robot learning and assistive teleoparation. In a

Fig. 1. A DrRobot Jaguar 4x4 robot can be teleoperated to climb a step.

human-robot collaborative study it was actually demonstrated that eligible robotic movements (rather than predictable or functional ones) mediated more fluent collaborations with humans (Dragan et al. 2015).

Another interesting idea is that of understanding each other's capabilities interactively. Awais and Hernich (2013) give a very interesting example of interaction based on human intentions. They suggest a framework where the robot starts reacting by copying human movements. With each repetition of the task the interaction improves by using history, action randomness, and heuristic-based action predictions. Specifically in the case of assistive robotic arms, a major issue is how to collaborate with a dexterous and complicated robotic arm by only using a simple joystick. Mapping a high-dimensional system to low dimensional inputs can definitely be a barrier for collaboration. Time-optimal mode switching could create a level of shared control and allow user to express their intentions (Herlant et al. 2016).

3 RESEARCH PLAN

Taking into account the body of literature discussed above, we propose a research plan that assumes these findings as a starting point to develop the technical capabilities for communicating intentions and shared control. To make this more concrete, we consider a specific collaborative task, and, namely, the task of teleoperating a rover robot to climb a step (Figure 1). The robot's wheels are big enough to clear the step, but some caveats are there: the operator needs to approach the step at an appropriate angle and speed, or the platform will slam against the step rather than raise its wheels over it; a sudden acceleration or sharp turn during the manoeuvre can overturn the robot; but the manoeuvre cannot be performed slowly, as there comes a point when the wheels do not touch the ground and the platform needs to have picked up enough speed to get on the step.

This simple experiment becomes more interesting when setup in a way that control is shared between the operator and the robot: the robot uses its accelerometer to predict that some teleoperation has the potential to overturn it, and should refuse to carry out the command. The operator, on the other hand, has the understanding of the dynamics behind climbing a step that is tall enough to be possible but challenging.

The actual demonstration task that will be used to collect data will be to challenge novice users to teleoperate the robotic platform up a step. Initial experiments have shown that managing to teleoperate the robot up the step in Figure 1 requires skilled manoeuvres, and that novice users can either operate the robot into dangerous inclinations or fail to accomplish the task. On the other hand, it is not straightforward how to implement such an autonomous skill for arbitrary, previously unseen steps and environments. We believe that this paradigm provides plenty of opportunities to study human-robot collaboration in a series of studies:

(1) *A non-anthropomorphic robot uses movement behaviour to communicate intentions to the user.* One such experiment is to compare how well different movement behaviours communicate robot 'objections' to executing a teleoperation command. For example, the robot might need to communicate a deviation from its plan (i.e., the operator is moving away from the goal set) or a more urgent safety concern (i.e., the operator requested an unsafe movement).

(2) *A robot understands user intention and correctly interprets teleoperation commands.* One such experiment is to develop and compare different strategies for interpreting the operator's intentions rather than blindly executing the detailed teleoperation commands. For example, the robot should use context and previous interactions with the user to decide if the operator's directive is to move against a step should be interpreted as a command to climb the step, to park by it, or to slam against it. Experiments will include understanding the trade off between making early and making safe predictions of the operators' intention, and adapting to different operators.

(3) *Integrating the above into a shared control interface.* These, more ambitious, experiment will synthesize communicating robot objections and human operation into a collaboration that achieves the goal.

At the current state of development, we have identified a hardware, an environment, and a task that is impossible for standard autonomous navigation, possible but challenging for experienced operators, and impossible for novice operators. We are currently developing the safety controls that will allow novice users to try the task without risking overturning robot, and will soon proceed to initial experiments along the lines described above.

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