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Physiological and subjective evaluation of a human–robot object hand-over task

Frédéric Dehais [a,*], Emrah Akin Sisbot [c], Rachid Alami [c], Mickaël Causse [a,b]

[a] ISAE – Campus Supaéro, Université de Toulouse, DMIA, 10 avenue E. Belin, F-31055 Toulouse Cedex 4, France
[b] Inserm, Imagerie cérébrale et handicaps neurologiques UMR 825, Université de Toulouse UPS, CHU Purpan, Place du Dr Baylac, F-31059 Toulouse Cedex 9, France
[c] CNRS, LAAS, 7 avenue du Colonel Roche, Université de Toulouse, UPS, INSA, INP, ISAE, LAAS, F-31077 Toulouse, France

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ABSTRACT

In the context of task sharing between a robot companion and its human partners, the notions of safe and compliant hardware are not enough. It is necessary to guarantee ergonomic robot motions. Therefore, we have developed Human Aware Manipulation Planner (Sisbot et al., 2010), a motion planner specifically designed for human–robot object transfer by explicitly taking into account the legibility, the safety and the physical comfort of robot motions. The main objective of this research was to define precise subjective metrics to assess our planner when a human interacts with a robot in an object hand-over task. A second objective was to obtain quantitative data to evaluate the effect of this interaction. Given the short duration, the “relative ease” of the object hand-over task and its qualitative component, classical behavioral measures based on accuracy or reaction time were unsuitable to compare our gestures. In this perspective, we selected three measurements based on the galvanic skin conductance response, the deltoid muscle activity and the ocular activity. To test our assumptions and validate our planner, an experimental set-up involving Jido, a mobile manipulator robot, and a seated human was proposed. For the purpose of the experiment, we have defined three motions that combine different levels of legibility, safety and physical comfort values. After each robot gesture the participants were asked to rate them on a three dimensional subjective scale. It has appeared that the subjective data were in favor of our reference motion. Eventually the three motions elicited different physiological and ocular responses that could be used to partially discriminate them.
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1. Introduction

Human–Robot Interaction (HRI) is getting more and more attention since the barrier between humans and robots begin to fade. The design of the interaction becomes a major challenge when the robot and the humans coexist in the same environment and cooperate to achieve tasks together. Besides the safety and the comfort of the interaction, an important property that is often ignored in the literature is the distribution of the cognitive load in the interaction. In an “object hand over” task, often it is the human who decides where the interaction will happen and adapts himself/herself to the motions of the robot. Even though this behavior allows the human to manage the interaction, it also puts he or she in charge of managing the behavior of the robot, thus increasing his or her cognitive load and reducing the intuitiveness of the interaction. Therefore, we have developed Human Aware Manipulation Planner (Sisbot et al., 2008, 2010; Marin et al., 2008), a motion planner specifically designed for human–robot object transfer tasks. The novelty of this planner is that it takes explicitly into account the human. In particular, our planner computes a path towards a robot posture considering a number of criteria that are extracted from user studies (Koay et al., 2007; Dautenhahn et al., 2006) and from the proxemics theory (Hall, 1966). A first criterion is the legibility of the interaction as the object transfer must be as visible and predictable as possible. A second criterion is the safety of the interaction as the robot must stay as sufficiently far as possible and transfer the object in the safest way. A third and last criterion is the physical comfort of the interaction as the object has to be carried to a place where the human should not make too much effort to reach and grasp it. Indeed, the planner computes automatically the best position where the robot-to-human object transfer should take place by reasoning on human’s kinematic structure, field of view and preferences. It then computes the path to reach this position and synthesizes motor commands to execute the motion. Eventually our planner decides the moment when the robot-to-human object transfer should happen and when to release and retract.

Therefore, it becomes obvious that there is a need to design appropriate metrics for the tuning and the optimization of such criteria.

* Corresponding author.
E-mail addresses: frederic.dehais@isae.fr (F. Dehais), emrah.akin.sisbot@laas.fr (E.A. Sisbot), rachid.alami@laas.fr (R. Alami), mickael.causse@inserm.fr, mickael.causse@isae.fr (M. Causse).

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Various methods are used to assess HRI from qualitative and quantitative points of view. They aim at better understanding and improving the design of this interaction in terms of social acceptance, cognitive and emotional impacts. Classical user studies consist of measuring the participants' performance regarding the number of errors, the occurrence of conflicts (Dehais et al., 2009), reaction time and task completion rate: these metrics have to be tuned and adapted (Steinfeld et al., 2006) regarding the task (*e.g.* teleoperation, supervision…) Nevertheless, given the short duration, the relative ease and the qualitative aspect of our "object hand over" task, such classical quantitative measures based on accuracy or reaction time are unsuitable to compare the gestures. A more suited method is to obtain subjective data by submitting a survey or a questionnaire when interacting with a robot. A specific type of questionnaire consists of self rated scales that give multidimensional subjective inputs such as mental or physical effort, pleasantness, level of anxiety (…) induced by the interaction. This method offers both qualitative and statistical data as shown by Kanda et al. (2004) study where robot "eye" contacts and well synchronized humanoid motions were positively correlated with positive subjective evaluation. This is particularly true in two studies (Hayashi et al., 2007; Shiomi et al., 2007) respectively conducted in a train station and a museum: the large sample of analyzed questionnaires combined with some of the pre-cited metrics, has led the authors to assess with statistical evidences the ability of the robots to attract attention and to help or inform the user. Since numerous self rated scales exist, Bartneck et al. (2009) have recently proposed a standardization of five HRI key concepts: anthropomorphism, animacy, likeability, perceived intelligence and perceived safety. Although this approach is interesting, it may be too generic and it does not take into account some cognitive aspects (*e.g.* predictability of the robot actions…) or some "physical" aspects of the interaction such as the physical comfort. Eventually if the subjective self-reports are convenient and easy to use, their validity remains quite limited: the participants' answers may be influenced by *a posteriori* rationalization, their state of mind, and the desire to satisfy the researcher's implicit objectives (Bethel et al., 2007; Mandryk et al., 2006).

Therefore, a number of authors (Koay et al., 2007; Bartneck et al., 2009) propose to assess the robot gestures with complementary physiological data in order to provide cues both on the cognitive activity and on the emotional states (Causse et al., 2009; Granholm and Steinhauer, 2004; Collet et al., 2009). Indeed there is a growing interest in HRI to derive the user anxiety and stress from heart rate (Rani et al., 2002), blood pressure (Housman et al., 2007), electroencephalography (EEG) (Wada et al., 2005; Wilson and Russell, 2002), skin conductance response (Takahashi et al., 2001; Munekata et al., 2006), urinary tests (Wada and Shibata, 2006), pupillary dilation (Yamada et al., 1999), respiratory rate and respiratory amplitude and muscular activity (Itoh et al., 2006). An interesting approach consists of collecting both these latter objective data and subjective ratings (Nonaka et al., 2004). Probably one of the most convincing studies in HRI has been conducted by Kulic and Croft (2007) since the experimentation has been realized with a real manipulator arm and a large number of subjects ($n = 36$). The participants' responses to different robot motions were collected using a 5 points Likert subjective scale and three physiological sensors (myogram activity on the eye brow, electrocardiogram, and skin conductance). Although the subjects were passive as they did not interact with the robotic arm, they have reported less anxiety, felt calmer with the safe robot motion, and showed significantly lower skin conductance value. On the contrary, fast motion has elicited strong physiological responses. Whereas most of the physiological studies in HRI are focused on the assessment of the emotional state of the user, very few have considered the physical comfort, such as the muscular effort (West et al., 1995) induced by the interaction. Moreover, most of these research using electromyograms (EMG) are biofeedback or neuromuscular assistance oriented (Merletti and Parker, 2004). Eventually, to the author knowledge, no studies have derived behavioral data from eye-tracking techniques despite visual perception is essential to interact with robots (Kulić, 2005).

A limited number of studies in HRI have explored human interacting directly with a physical humanoid or mobile robot (Bethel et al., 2007), and in this perspective we have developed Jido, a real "pick-and-place" robot. For the purpose of the experiment a reference motion, which entirely suits *a priori* adequate legibility, safety and comfort criteria, has been integrated to our planner. In addition, two other robot motions, combining different levels of legibility, safety and physical comfort values, were conceived to compare them with the reference motion. The first objective of this study was to rate our reference gesture from the other ones using self-reports of legibility, safety and physical comfort. The second objective was to assess the effects of the three gestures on the participant's galvanic skin conductance response, the deltoid activity and ocular activity. Considering that the interactions with the robot were quite short, the galvanic skin conductance response was chosen as the skin phasic response is highly dynamic with short response latencies (Kulić and Croft, 2007; Rani et al., 2002). The deltoid activity measurement was selected as this muscle starts the forward raising of the arm when the participant interacts with the robot. Eventually the eye movements were recorded using an eye tracker as this technique is a relevant indicator of task complexity (Wilson and Eggemeier, 1991).

2. Materials and methods

2.1. Participants

Healthy volunteers ($n = 12$) were recruited by local advertisement. Inclusion criteria were: young (mean age: 26.5 ± 5.35) male ($n = 10$) and female ($n = 2$), right-handed, postgraduate (mean years of education: 19 ± 2.15). Non-inclusion criteria were sensory deficits, neurological, psychiatric or emotional disorders and/or being under the influence of any substance capable of affecting the central nervous system. No grants were offered to the volunteers for their participation to the experiment. The participants gave their informed consent after having received complete information about the nature of the experiment.

2.2. Experimental set-up

The experiment took place in a vast empty room with human oriented toward the robot and the wall to avoid any possible disturbances that might occur during the study. The experimental set-up was composed of Jido (Fig. 1), an MP-L655 platform from Neobotix, equipped with a 6°-of-freedom Mitsubishi PA-10 arm. Several sensors were available on the platform: sonars, two laser range finders, two stereo camera banks (one mounted on the arm and the other on a pan-tilt unit on the base platform), several contact sensors and a wrist force sensor. The Human Aware Manipulation Planner is integrated to Jido robotic platform in LAAS/CNRS.

2.3. Motions' descriptions

The participants were subjected to three different types of object hand-over robot motions. The motions were separated by their speed (also by the acceleration and jerk), their shape and the moment to release the object.

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