Shared trajectory planning for human-in-the-loop navigation of mobile robots in cluttered environments

Carlo Masone, Antonio Franchi, Heinrich H. Bülthoff, Paolo Robuffo Giordano

I. ABSTRACT

The advances made in the last two decades have allowed robotic platforms, and in particular mobile robots, to successfully address a large variety of tasks, albeit mainly repetitive and simple ones. However, real-world applications typically involve complex decision making processes and non structured environments thus requiring a level of perception/world awareness and cognitive capabilities that cannot yet be provided by a robot. For this reason it is convenient, if not mandatory, to have a human supervising the execution.

The *robot shared control* framework (see, e.g., [1], [2]) represents a promising step in this direction, since it allows to merge robots (limited) autonomy and humans cognitive capabilities. Previous studies have applied this idea to mobile robots navigating in cluttered environments, with an emphasis on *bilateral shared control* architectures with *haptic feedback* for the human operator. Typically, the operator commands a motion (desired position, reference velocity) to the robot via a haptic device. The robot executes the command while retaining some autonomy in order to, e.g., avoid obstacles or other dangers. Finally, the loop is closed by rendering on the haptic feedback a force that is proportional to the mismatch between commanded and executed motion in order to increase the operator's situational awareness.

Despite being an effective approach, commanding direct motion inputs requires a high commitment of the human, especially when the task is very complex or the environment is highly cluttered. Therefore, we propose an extension to the shared control in which an operator acts at the planning level, in order to modify some characteristics of the task but without the burden of directly driving the robot [3]. We assume that a task scheduler generates an initial trajectory based only on prior information. The trajectory is described as i) a geometric path $\boldsymbol{\gamma}(\boldsymbol{x}, s)$, where $\boldsymbol{x} \in \mathbb{R}^n$ is a set of parameters uniquely determining the shape of the curve and $s \in \mathbb{R}$ is an arc-length like parameterization, and ii) a timing law $s(t)$ that defines the traveling speed on the path. The operator can then modify online the path and timing law, accounting for the new information that becomes available. The complexity of manipulating the shape is decreased by using an invertible map from a limited number $m \leq n$ of controls to the set of parameters $\boldsymbol{x}$, allowing the user to command some global behavior, e.g. translations or rotations of the curve.

At the same time, the robot must track the generated trajectory and, whenever needed, modify it in real time in order to avoid collisions or to reach a nearby target. In particular, the robot performs both a reactive deformation of the reference trajectory and a planning of alternative paths.

Finally, the bilateral component of the human-robot interaction is realized by feeding back to the operator a force cue informative of the *global* deformation acting on the desired path rather than on a *local* mismatch between commanded and executed position/velocity.

Summarizing, the novel elements of this approach are: i) broadening the classical shared control approach by endowing the mobile robot with a higher planning autonomy, ii) allowing a human operator to act at the planning level rather than at the motion control level, iii) generating a force cue informative of the global deformation of the desired path rather than of the mismatch between direct motion commands and their execution. The proposed method has been extensively tested with human/hardware in-the-loop simulations, featuring a physically simulated quadrotor aerial vehicle and a haptic device (see Fig. 1).

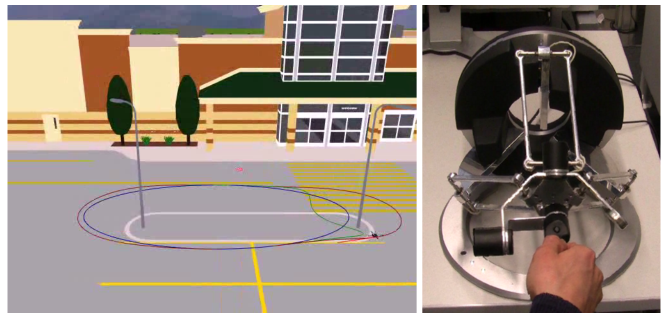

Fig. 1: simulation setup for human/hardware in the loop simulations. a): simulation environment. b): haptic device used to command the task path and feed back forces.

C. Masone, A. Franchi and P. Robuffo Giordano are with the Max Planck Institute for Biological Cybernetics, Spemannstraße 38, 72076 Tübingen, Germany {carlo.masone, antonio.franchi, prg}@tuebingen.mpg.de.

H. H. Bülthoff is with the Max Planck Institute for Biological Cybernetics, Spemannstraße 38, 72076 Tübingen, Germany, and with the Department of Brain and Cognitive Engineering, Korea University, Seoul, 136-713 Korea. E-mail: hhb@tuebingen.mpg.de.

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