Modeling Humans in the Teleoperated Robot System Loop

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I. Introduction

Teleoperation (in direct and advanced forms) is the default mode of control for robotic tasks requiring human judgment and decision-making skills. Even in cases where autonomous operation is possible, some operators prefer to remain in the control loop to quickly access and interpret the information gathered by the robot [1]. Therefore, despite recent advances in robot autonomy, teleoperation continues to be a relevant robot control modality for the foreseeable future.

A system-level model of the teleoperation process must incorporate a model of the human operator in addition to the robot model. Figure 1 shows a block diagram of a teleoperated robot with an operator in the control loop, and indicates that it has an inner loop/outer loop control structure, with the human in the outer loop and the robot processes in the inner loop. Note that this block diagram is general enough to represent a wide spectrum of teleoperated systems, with varying levels of autonomy. While the model of the robot can be derived from physical laws and algorithmic rules, it is often difficult to reliably model the behavior of a human operator.

Accurate models of operator behavior and performance could enable robot designers to take a more holistic approach to developing teleoperated robots by indicating how design choices (such as hardware components, algorithm implementations, and user interfaces) impact the overall system performance without the need for extensive, costly user tests.

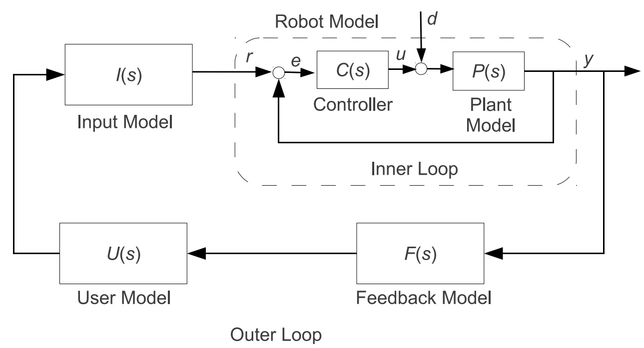

Fig. 1. Block diagram showing the elements in a teleoperation control loop, represented here as transfer functions. The robot's processes (including all levels of autonomy, if present) run in the inner loop, while the operator provides the control for the outer loop.

II. Background

Modeling human driver behavior has a rich history in the automotive domain [2]. From transfer functions models to nonlinear and adaptive controllers to neural networks, genetic algorithms, and fuzzy logic controllers [2], there are myriad methodologies for modeling vehicle lateral control (steering), longitudinal control (acceleration and braking), and combined control. These models can be used to simulate human drivers when testing new vehicle designs and technologies [2], and despite the complexity of human behavior, low order models are often sufficient for many control tasks [3].

In the field of Human-Computer Interaction, there exist laws quantitatively modeling human performance under different scenarios. Notably, Accot and Zhai [4] developed a law (derived from Fitts' pointing law) showing that the time T to steer through a path is governed by $T = a + bID$, where a and b are constants and ID is a difficulty index. It has been shown that this law also holds for locomotive steering tasks in virtual environments [4].

III. Proposed Research

While we can draw inspiration from previous studies in other domains, the resulting models have been developed for tasks dissimilar enough from teleoperation that they cannot be used directly. For example, automobile drivers receive feedback that includes visual cues, motion effects, sound, and tactile information [2], whereas only limited visual signals are typically available during teleoperated driving. It is therefore desirable to develop a set of models describing how humans interact with robots in the context of teleoperation.

Depending on the task and modeling objectives, these human operator models will take multiple forms, from simple mathematical relations (like Fitts' law) to transfer functions to statistical models. These models may also be combined together for missions that require multiple operating modes such as mobile manipulation, which combines arm movement and chassis navigation.

Models will be developed by performing user studies for generalized telerobotic tasks (such as steering, pointing, and orienting) on simulated and real robot systems under variety of conditions, including video quality, system latency, and input and feedback modalities. The task performance results and user behavior will be used to develop the operator models, which will also consider user demographics and ability/experience. Model validation can be performed on the generalized tasks as well as more specific and complex scenarios combining multiple models, such as remote hole drilling.

IV. Impact

If implemented, this work would result in a library of models describing human performance and behavior for teleoperation tasks under a wide range of conditions.

When combined with models of the robot hardware and software, user models would allow designers to simulate a complete closed-loop teleoperation system. This would highlight problems in the loop (such as excessive latency or underpowered actuators) that could lead to system failure. Additionally, potential design choices could be evaluated on a wider scale, and parameter tuning could be performed at a higher resolution than is feasible with humans in the loop. If necessary, user studies could later be performed on a reduced set of design variables. These models could also be used as a basis for comparing novel telerobotic input and feedback devices to currently fielded user interfaces. Finally, if the implementation of an autonomous behavior is treated as a design choice, the overall system model can be used to determine the appropriate level of autonomy, and over time facilitate an efficient shift from teleoperated to more autonomous control.

V. Example: Teleoperated Steering

My previous research [5] showed that a human teleoperator's steering behavior for a simulated robot under different types of latency could be modeled as a PD controller based on a projected lateral displacement signal. This model was then used to generate human-like steering inputs to a simulated robot in real time, and it was found that the controller's behavior and performance was similar to a human operator's under multiple latency conditions. This model could be used in the future to generate steering commands to simulate the system performance of different robot designs without the need for extensive testing with users. Further studies could also incorporate longitudinal control into the model, giving a more complete picture of operator driving behavior under different types of delay.

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