AN IDENTIFICATION TECHNIQUE FOR ADAPTIVE SHARED CONTROL IN HUMAN-MACHINE SYSTEMS

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Abstract

The NavChair assistive navigation system [1, 2] is being developed to meet the needs of multiply handicapped people who are unable to operate available wheelchair systems. The NavChair shares control with users by allowing them to achieve desirable motion while overriding unsafe maneuvers.

An outgrowth of this project is an investigation into methods of adaptive shared control. In particular, methods of autonomous mode selection based upon observations of user behavior are being studied. This paper presents a modeling approach to monitoring human control behavior in real time; preliminary experimental results evaluate its ability to distinguish human control behaviors in a simulated system.

Introduction

Like many human-machine systems, the NavChair assistive navigation system takes advantage of the capabilities of both the user and the machine by allowing them to share control of system output [3]. An important characteristic of human users is that they are able to adapt their control behavior to changes in environmental conditions and functional requirements. By allowing users to share control of the system, their adaptability improves the versatility and robustness of the entire system. An ability to estimate and facilitate human adaptation could be used to reduce user workload and increase the range of system adaptation.

Machine adaptation involves control system changes in response to estimates of system state and user behavior patterns. Figure 1 illustrates an example of a situation in which the NavChair must adapt by changing its control mode. In this case, environmental inputs do not uniquely determine control mode selection, so this decision must also be based upon an evaluation of user behavior. This paper presents a method of monitoring human control behavior in real time and evaluates this method experimentally.

Methods

An ability to model human control in real time would improve the design of machines that must recognize and adapt to changes in human control behavior. Standard system identification provides real-time human models when input and output data are available, such as in instrument-based manual tracking [4]. Most human-machine systems, however, have unmeasurable input that is generated spontaneously by the person [5]. A wheelchair user, for example, integrates a wide variety of sensory signals to produce system input: the target path. Our goal is to develop a method of human control behavior monitoring that does not require knowledge of system input.

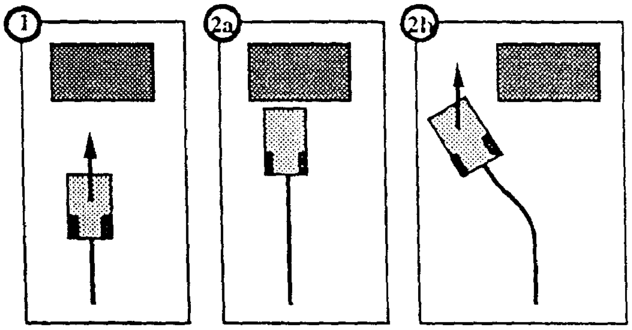

Figure 1: Mode Selection. The NavChair must be able to perform mode selection in the absence of environmental cues. Frame (1) shows the NavChair approaching a desk. One of two outcomes is possible: either (2a) the NavChair 'docks,' allowing the user to access the desk, or (2b) the NavChair performs an avoidance maneuver and continues to move forward. These two behaviors correspond to two different modes of operation, close approach and obstacle avoidance, that cannot be performed simultaneously.

We present an approach that allows reactive processes in human control to be modeled in real time. Figure 2 illustrates a model of a human-machine feedback loop in which the user perceives path errors relative to the target path and generates a command to correct the path of the wheelchair. We hypothesize that corrections in response to applied disturbances provide enough information to permit quantitative human modeling.

The experiment described in this paper was designed to demonstrate how reactive human models can be used to detect human adaptation in real time. The controlled system was a simulated wheelchair viewed from above in a world of walls. As the wheelchair "moves" the walls scroll by. The orientation of the world remains constant with respect to the screen and the orientation of the wheelchair is shown to change. The wheelchair dynamics and kinematics are the same as those of the NavChair.

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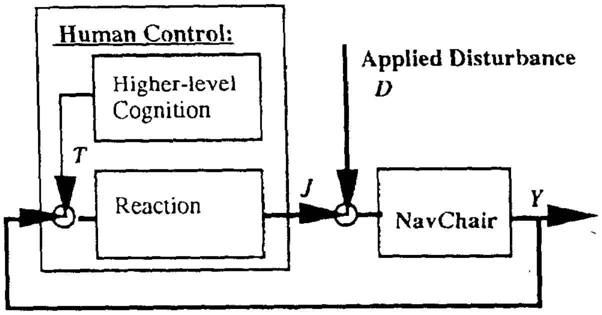

Figure 2: Human Reactive Control Loop. The human reactive control loop is where deviations from the target path are perceived and corrected: the actual motion of the chair, Y, is compared to the target path, T, to produce a joystick command, J. Observations of responses to an applied disturbance, D, are used to model the behavior of this feedback loop.

Two subjects were asked to drive a simulated wheelchair through a course consisting of a series of hallways and rooms as quickly as possible. The hallways were obstacle-free and the rooms had one obstacle each which required the wheelchair motion to deviate from straight. A time penalty was assessed for collisions with the walls. Because collisions were more likely in narrow hallways, we hypothesized that lateral control performance would be better in the narrow hallway and that reactive human modeling would allow this change to be detected in real time. Note that this analysis is similar to one method of monitoring visual fatigue [6] but the underlying modeling approach is substantially different.

Analysis

Joystick position and disturbance input data were recorded at 30 msec intervals. In addition, the environment type (i.e. hall or room) was recorded for each time step. An autoregressive model (1) relating applied disturbance, D, to joystick position, J, was identified for each data set, where subscript 0 corresponds to the current data sample, 1 to the most recent sample, etc. System identification calculates parameters a_i and b_i through least-squares regression of observed data pairs, D and J. [7]

$$J_0 = -\sum_{k=1}^{N_a} a_i J_i + \sum_{k=0}^{N_b} b_i D_{(i+N_k)} \qquad (1)$$

Subsequent human control behavior was analyzed by comparing actual and predicted joystick behavior. The goal of this analysis was to evaluate how well the identified model explained joystick behavior at each time step, using only previous data. Predicted joystick behavior was calculated by using recorded values of D and the identified values of a_i and b_i in equation (1). The difference between these values was smoothed using a 1.5 Hz low-pass IIR filter, rectified and thresholded.

Results

Table 1 summarizes correlation data between actual and estimated wheelchair environments. Note that hallways were misidentified as rooms only when entering or leaving a room. In other words, the behavior of the human appears to adapt to the open room environment just before entering the room. The delay in adaptation when leaving a room could be an artifact of data processing delays.

Environment	ID	Subject 1	Subject 2
Room	correct	80%	86%
	incorrect	20%	14%
Hallway	correct	94%	92%
	incorrect	6%	8%

Table 1: Correlation of actual to estimated user environment.

Conclusions

The development of more effective assistive technologies will require advances in our ability to estimate and react to changes in human control behavior. The preliminary results presented in this paper indicate that human modeling warrants further investigation as a potential method to monitor human control behavior in real time for use in adaptive shared control systems, such as the NavChair.

Acknowledgments

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