THE ROLE OF USER MODELLING IN REHABILITATION ROBOTICS

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Abstract

Most existing user models concentrate specifically on able-bodied users interacting with computers. This paper examines the relevance of such models to Rehabilitation Robotics and the implications for practitioners in the field. It addresses current research to adapt such models specifically to rehabilitation applications, including observations from extensive user trials.

Introduction

The key to good design is the inclusion of user studies and usability testing early in the design process. These are often in the form of regular user trials and facilitate consideration of the loads, both physical and cognitive, on the user.

The origins of user modelling are in neuropsychology and the attempts to understand the brain and its functions through empirical models. User models have since been adapted for use in the field of man-machine interfacing and several models exist, such as the keystroke level[1] and GOMS[1] models, for describing human-computer interaction in particular.

In this paper, a relatively simple model, the Model Human Processor (MHP), will be considered.

The MHP Model

The MHP model postulated by Card et al[1] describes the functioning of the brain in terms of perception, cognition and motor functions. Response times to stimuli are described by the following human interaction cycle equation:

$$\text{Total time} = x\tau_p + y\tau_c + z\tau_m$$

(where x, y and z are integers)

τ_p, τ_c and τ_m correspond to the times for single occurrences of the perceptual, cognitive and motor functions. For a relatively simple task, such as pressing a key in response to a screen flash, the coefficients in the above equation are all one.

However, a more complex task, such as classifying a symbol as either letter or number, requires more cognitive cycles and consequently the τ_c coefficient increases. Experimental data from able-bodied subjects shows that average times of 100ms (50~200ms), 70ms (25~170ms) and 70ms (30~100) are seen for each perceptual, cognitive and motor cycle respectively. It is anticipated that equivalent data for disabled users will become available from user trials in the near future and that the greatest disparity will be in the motor times.

The MHP model in use

This model has been calibrated to describe human-computer interaction for able-bodied users, but also offers interesting insights that are of use in Rehabilitation Robotics.

For example, assuming that the perceptual cycle time is similar for able-bodied and motion impaired users, then a guideline for the maximum response time that a robot system should have before it can claim real-time response can be deduced. For this, the time between the completion of the user command and the robot beginning to respond must be significantly less than the 50ms minimum perceptual response time.

Other user models

This is a relatively straightforward example of how such a user model can be used in the deeper understanding of the interactions in a man-machine interface. For more complex scenarios, it is helpful to take the model to a higher level of detail or construct a more specific model for that particular task type, such as the keystroke level model for keyboard input[1].

A common feature of most user models is the segmentation of user actions into discrete, quantifiable chunks that can be combined to describe any action performed by the user in a particular task environment. Models of this type rely upon the assumption of statistical independence between each discrete chunk.

The role of user trials

User model theory is a very useful starting point for understanding the user. There is, however, a question over the degree to which discretisation of parameters is possible. For example, in the MHP model there is an overriding assumption that the various stages in the interaction cycle are entirely independent. It is thought that motor control is governed by negative feedback control loops[2] and this throws the assumption of independence into doubt, although the degree of correlation may be statistically insignificant.

It is therefore necessary to validate user models and verify any theoretical predictions from them through contact with potential users in trials.

Example empirical observations

Experimental data was gathered during a series of user trials conducted at the Papworth Trust using Jester, a gesture input system[3]. These trials were intended primarily to validate the use of gestures as a feasible alternative source of input[4] and yielded substantial interaction data from seven users with a range of disabilities and severities.

Users were given two types of tests to perform, one of mouse emulation through gestural input[3], and the other to study the production of gestures. It is not proposed to discuss the methodology here, but to summarise some of the observations made.

Physical user load

One of the Papworth tests involved an incremental increase in complexity of the task involved, moving from producing single gestures in one mode of input to combinations of gestures across several modes. The corresponding input times and gesture recognition rates were subsequently calculated and compared.

It became clear from analysis of the results that as user physical load was increased, performance, in this case the number of successfully recognised gestures, began to decrease. As shown by the human interactive cycle, every physical motion has a cognitive process associated with it. Therefore, the decrease in performance seen can be interpreted as being a result of cognitive overload, as cognitive processes govern the production of the physical movement.

It is therefore important to adopt techniques to minimise such loading on the user. Where an option existed for the users to reduce such loading on themselves, for example by producing gestures sequentially instead of simultaneously, they invariably took it, despite effectively doubling the time taken per input in this case.

Cognitive user load

Cognitive overloading does not necessarily have to derive from physically taxing tasks. The mouse emulation test involved moving a cursor around the screen using head movements under either position or velocity control (PC and VC respectively). PC required greater physical effort from the users, but offered quicker response times. VC was easier to manipulate physically, but more difficult to understand conceptually.

When asked which control method they preferred, the majority of the users expressed a preference for the position control. This was in direct contradiction to the physical loading of each control method. VC offered easier physical control of the cursor, but the cognitive processing required to decide which movement to make to control the cursor was sufficient for the users to feel overloaded by it. Only in the severest cases, when position control was virtually impossible, was velocity control the preferred option.

The evidence of cognitive overloading is reflected in the respective recognition rates for each method of mouse control, with slightly better performance being seen from PC.

Overloading, both cognitive and physical, will result in users disliking the system, even if it offers them greater functionality or ease of use in the long-term. Under these circumstances the MHP equation probably begins to break down as the cognitive stage becomes decreasingly linear and the assumption of independence becomes increasingly strained. The MHP model can therefore be thought of as being bound-limited.

Constrained or unconstrained?

One of the recent trends in Rehabilitation Robotics is towards less structured interaction between users and the target system. This is a laudable aim, but it cannot be assumed that it is possible to expose a user to such a system and expect immediate results. Users, particularly those with motion impairments, are generally reluctant to produce all-encompassing inputs for fear of going wrong. They prefer incremental input strategies, where they feel more in control of the progression of the work by small steps, so that any mistakes committed en route can be corrected relatively easily. A completely unconstrained workspace is likely to be daunting. This is not an insurmountable problem, but it must be borne in mind that a large investment in training will be required to overcome this, otherwise performance will be degraded.

This is not to advocate completely structured approaches either; users need to feel in control of their surroundings. A compromise between the two is required, for example McEachern's shared control strategy [5].

Current work

Research is focussing on calibrating the MHP model for disabled users and the development of more specific models. It is intended to also answer questions such as whether cognitive loading through physical effort is greater for the physically disabled.

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