Statistical estimation of user's intentions from motion impaired cursor use data

P Langdon[1], S Godsill[2] and P J Clarkson[3]

[1,3]Engineering Design Centre/[2]Signal Processing and Communications Laboratory,
Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, UK

[1]*pml24@eng.cam.ac.uk*, [3]*pjc10@eng.cam.ac.uk*, [2]*sjg@eng.cam.ac.uk*

[1,3]*www-edc.eng.cam.ac.uk*. [2]*www-sigproc.eng.cam.ac.uk*

ABSTRACT

We report the application of new statistical state space filtering techniques to cursor movement data collected from motion impaired computer users performing a standard Fitts's Law style selection task. Developed as an alternative to expensive haptic feedback assistance, the aim was to assess the feasibility of the basic techniques in resolving the users intended trajectory from the extremely variable and wavering data that result from the effects of muscular spasm, weakness and tremor. The results, using a choice of basic parameter for the filters, show that the state space filtering techniques are well suited to estimating the intended trajectory of the cursor even under conditions of extreme deviation from the direct track and that these filters effectively act as an extreme cursor smoothing system. We conclude that further development of the approach may lead to more effective adaptive systems capable of providing smoothed feedback to the user and estimates of intended destination. A similar approach might further be applied to situationally induced movement perturbations.

1. INTRODUCTION

Current computer input systems are often difficult for users with motion impairment to access. Impairments can result from athetoid, ataxic and spastic Cerebral Palsy, Muscular Dystrophy, Friedrich's Ataxia, Tetraplegia, spinal injuries or disorder, Parkinson's disease, stroke and arthritis. Frequent symptoms include tremor, spasm, poor co-ordination, restricted movement, and reduced muscle strength. Computers offer greater freedom to participate in education and leisure activities, as well as increased job potential and satisfaction. The Internet is a prime example that offers a great opportunity for disabled users (Nelson, 1994) enabling dialogue that is entirely independent of the ability to speak clearly, and eliminates prejudices based on appearances. We investigate ways in which computer access for people with such conditions may be improved through the use of software based cursor trajectory filtering and smoothing. Previous work in Computer Access for Motion Impaired Users we have carried out, aimed to characterise motion-impaired users and test methods for making computers more accessible, such as force-feedback. The aim of the present work is to focus on an alternative approach, that of software modification of impaired cursor motions using some of the original unassisted cursor movement data.

2. BACKGROUND

The available body of academic theory in HCI and user modelling concentrates almost exclusively on able-bodied users. There are a number of original input approaches such as head movement input (LoPresti00) and EEG scanning (Moore, 2000), but these are often expensive and frequently do not match the typical actions required to interact with a GUI (Sears, 2003). An approach that is complementary to the user's preferred input device may be more productive. One approach that offers significant potential is haptic feedback, particularly force feedback with easily available low-cost haptic devices (Dennerlein, 2000, Langdon, 2002). However, this requires the use of a mechanical, electromagnetic device to generate the instantaneous forces required. A more inexpensive solution is visual feedback resulting from software assisted cursor smoothing tested with motion-impaired movement.

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As a first step to investigating this possibility we have analysed some motion-impaired cursor movement data from previous studies with haptic feedback systems. To pursue this, unassisted cursor movement data was derived from our previous work and used to test the effectiveness of advanced techniques for enhancement derived from them, namely state-space filtering. The aim was to develop and evaluate software methods of enhancing situational and health induced motion-impaired movement for dissemination to the motion-impaired and software development communities.

2.1 Force Feedback Studies

This paper builds on previous work done under the original Computer Access for Motion Impaired Users project, whose aim was to characterise motion-impaired users and test methods for making computers more accessible, such as force-feedback. Techniques aimed at enhancing cursor movement for motion impairment will also impact cursor use for able-bodied users during conditions of situationally induced perturbation or vibration. Such conditions are encountered, for example, in the use of mobile devices on vehicular transport. Current interface design practices are based on user models and descriptions derived exclusively from studies of able-bodied users. However, such users are only one point on a wide and varied scale of physical capabilities. The overall aim of this research is to contribute to the enhancement of accessible input systems and interfaces. Our previous CAMIU research (e.g. Hwang, 2002, 2005) has shown that there are very important differences between those with motion-impairments, be they elderly or disabled, and able-bodied users when they interact with computers, and that motion impairment may be ameliorated by force feedback ("Haptics": See Figure 1). In addition, ordinary users may be disabled by environmental factors. The attentional, perceptual and physical demand of mobile interactions gives rise to a Situationally Induced Impairment and Disability (SIID), contrasted with Health Induced Impairment and Disability (HIID) (Sears, 2003). We focus on investigations of software-based enhancements of cursor movement for all motion-impaired users, particularly those who are health impaired.

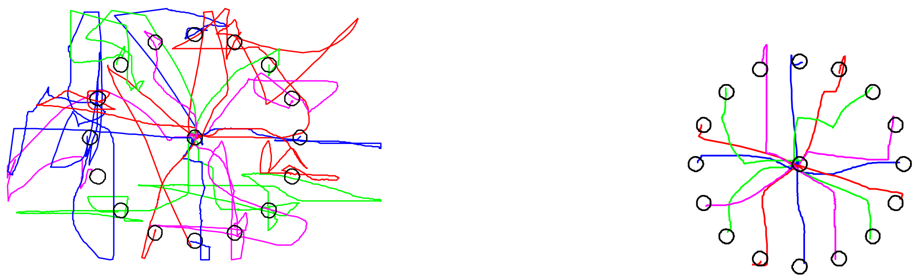

Figure 1. *Cursor Movements of a Motion Impaired user to select a target in an undamped (left) and force-feedback damped (right) condition.*

2.2 Pointing Task

Performance in pointing tasks is most commonly evaluated using speed and accuracy. Although traditional measures may show that a difference exists between conditions for impaired movement, establishing why they exist is more likely to be accomplished by analyzing the path of movement throughout a trial in conjunction with conventional measures (Langdon, 2002, Hwang, 2004). Users may trade speed against accuracy, achieving an optimised number of sub-movements that is often about two with able-bodied subjects (Meyer, 1990). Such a model may also be applicable to the analysis of haptically modified cursor movement where impaired motion can be characterised as consisting of multiple slow trajectory jumps separated by breaks during which users assess their own performance under conditions of perturbation from their motor system (Hwang, 2005).

2.3 State Space Trajectory Estimation

For several decades researchers have studied the estimation of state trajectories in state-space or dynamical models (`filtering'), using Bayesian filtering methodologies such as the classical Kalman filter. In recent years, the massive increases in available computational power have led to rapid advances in both tracking methodology and applications; in particular, the development of Sequential Monto Carlo (SMC) methods that are readily able to handle non-linear, non-Gaussian models in a vast range of applications from audio signal processing, through to computer vision and robotics (Liu, 1998, Doucet, 2000, Godsill, 2004). These methods are particularly strong candidates for the cursor movement application, since they automatically store a randomised range of hypotheses about the tracking parameters when the data are ambiguous (See Figure 2).

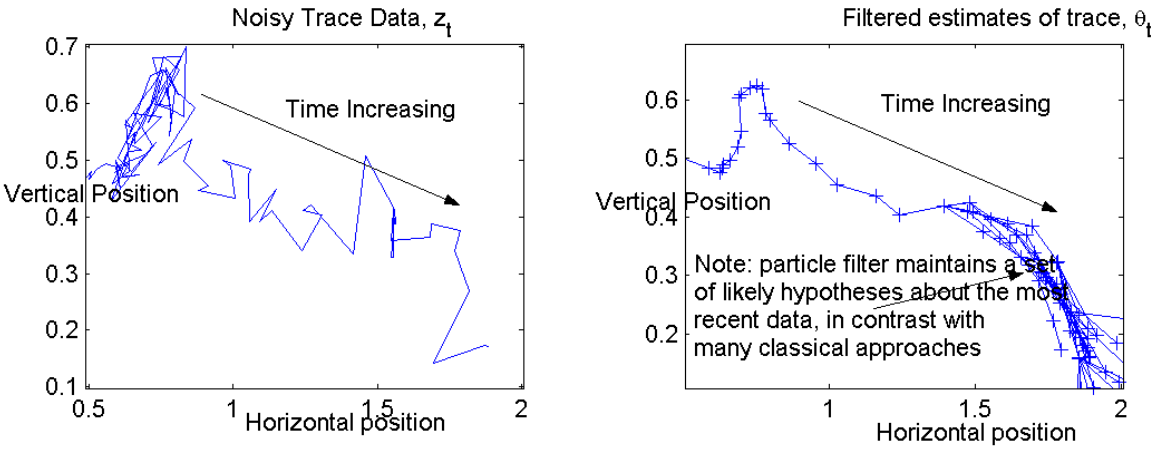

Figure 2. *Left hand side: Noisy trace data z_t generated from a near-constant velocity model in Gaussian noise (range/bearing domain). Right hand side: estimated paths $\boldsymbol{\theta}_t$ using variable rate particle filter. (Godsill04b). Note the models automatically adapt in the presence of 'tremor' like behaviour.*

A state-space modelling approach provides a methodology to explore the determination of cursor characteristics by adaptation of model, or 'state' parameters. This can be carried out in conjunction with experimental determination of the effectiveness of 'filtered' performance, in particular, improvements over no-assistance and force-feedback conditions and under conditions of situational impairment such as vibration. The results of the initial studies can then be used to arrive at an algorithm capable of assessing the extent to which modification of the filtering parameters alone is adequate before the interface elements themselves need to be modified. In the most basic state-space modelling approach, we wish to estimate a user's desired cursor position at a time **t**, say $\boldsymbol{\theta}_t$. In the simplest setting, the user's next move to $\boldsymbol{\theta}_{t+1}$ may depend only upon the current position $\boldsymbol{\theta}_t$, (which would be an x-y coordinate) through a conditional probability law, $f(\boldsymbol{\theta}_{t+1} \mid \boldsymbol{\theta}_t)$. Appropriate models for this might be the nearly-constant velocity laws applied commonly in radar tracking (Bar-Shalom, 1988). We then need to specify an observation of the move the user actually makes, given his intended move to $\boldsymbol{\theta}_{t+1}$. This again will be a random process, depending on the type of motion-impairment and/or environmental disturbances present. The probability distribution of the new measured position $\mathbf{z}_{t+1}$ might in the simplest case depend only on the desired position $\boldsymbol{\theta}_{t+1}$, through a probability density function $g(.|.)$, so that the entire system could be summarised in standard probabilistic state-space form as follows: -

$$\boldsymbol{\theta}_{t+1} \sim f(\boldsymbol{\theta}_{t+1} \mid \boldsymbol{\theta}_t) \quad (1)$$

$$\mathbf{z}_{t+1} \sim g(\mathbf{z}_{t+1} \mid \boldsymbol{\theta}_{t+1}) \quad (2)$$

Once appropriate distributions are specified for f () and g () above, Bayesian filtering can be applied to the above model in order to estimate the desired position z_t.

3. RESULTS

As a baseline test, we adapt a class of tracking models first presented in Godsill and Vermaak (2004,2005), in which the user's intended cursor path obeys a dynamic model expressed in terms of its instantaneous heading angle in the x-y plane of the monitor and the distance moved along the path. The desired trajectory is modelled as a point mass moving in a plane in a viscous medium, and subject to random forcing parallel and perpendicular to its path. The forcing is piecewise constant relative to the heading angle and subject to random change at random time instants. Such a model has been found appropriate for manoeuvring craft in tracking applications, and here we adopt it for its flexible characteristics and easy implementation within a SMC framework. This model, known as the intrinsic coordinate model, specifies the form of the dynamic model $f(\boldsymbol{\theta}_{t+1} \mid \boldsymbol{\theta}_t)$ for the user's desired cursor trajectory. We now specify a model for the user's observed behaviour, conditional upon their desired path. We adopt a very simple behavioural model that assumes the user has visual feedback of where the mouse trace is currently placed, z_t , and where the desired position should be, $\boldsymbol{\theta}_t$. The user then attempts to move the cursor to the desired position, but makes a random error, both in magnitude and direction of the move. The assumed statistics of the error are used to specify the likelihood function $g(z_{t+1}| \boldsymbol{\theta}_{t+1})$. Having specified the dynamical model for the desired cursor trajectory and the observation (dynamical) model for the actual path followed, we may then infer the desired path using a Bayesian filter, i.e. we obtain recursively an estimate of the 'filtering distribution', $p(\boldsymbol{\theta}_t|z_{1:t})$. This is implemented using a special version of the sequential Monte Carlo filter, the variable rate filter (Godsill and Vermaak (2004,2005)).

Some example results from this setup are given in Figure 3 below, using three of the motion impaired trajectories from the set illustrated in Figure 1.

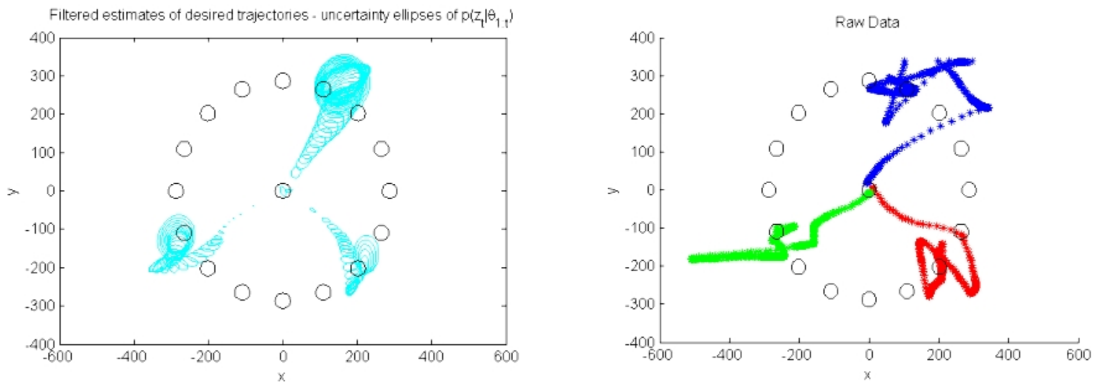

Figure 3. *Left hand side: filtered traces, showing confidence ellipses obtained from the sequential Monte Carlo filter. Right hand side: corresponding noisy trace data. Note that the filter has 'smoothed' much of the erratic jumping behaviour and quite clearly identified the user's intended destination, despite the ambiguity of the data.*

4. DISCUSSION AND CONCLUSIONS

This approach is an innovation in enabling access to computers for motion-impaired users that has not been researched in depth before. Previous work with able-bodied interface use has looked at trajectory analysis for prediction of the users' intended target (e.g. Oirshot, 2001) and trajectory prediction for telepointers under conditions of network latency delays (e.g. Gutwin, 2003). In the former approach, able-bodied trajectories proved to be essentially linear and velocity predictable while in the latter, encouragingly, trajectories for writing-like gestures were successful predicted up to delays of 80 msec and could be smoothed using Kalman filter predictors. Both able-bodied physiological tremor and pathological tremor, common in Parkinson's disease, have been addressed using Fourier software methods (Riviere96) with some success, indicating that software approaches are feasible for predictable motion-impairments with a repetitive oscillatory nature.

We have demonstrated the utility of the state space filtering approach with results from preliminary analysis of a range of motion impaired cursor movement traces taken under different conditions and proved the effectiveness of the technique for further development.

Following these findings, new models non-linear/non-Gaussian models can be proposed and tested using state-of-the-art sequential Monte Carlo methods. Further key developments that are possible include:-

1. **The effect of visual (and other) feedback**: there are many options for feedback of the filtering results to the user, depending on the extent to which the given (software) application is modified. For example, the estimated intended cursor position $\boldsymbol{\theta}_t$ could be displayed on screen in place of the actual physical cursor position $\mathbf{z}_t$, thus introducing elements of feedback into to the system;
2. **Direct determination of user's intentionality:** If it is possible to access to the configuration of the screen in an application then it will be possible to formulate and solve a more directed approach to user intentionality. One would then have a collection of dynamical models $f(\boldsymbol{\theta}_{t+1} \mid \boldsymbol{\theta}_t, D)$, one for each possible destination D, which can be built explicitly into the tracking framework;

3. **Automated parameter adaptation (unsupervised learning):** It might be possible to first model a number of different classes of behaviour and then estimate the correct class for a given user type. The class variable could be estimated as another unknown state of the system. Alternatively, a generic model could be specified that would then adapt automatically as part of the state-space model. In either case, improved performance could be expected, as the system would automatically adapt to the different characteristics of users.

4.1. Implications

The preliminary results suggest that State Space Trajectory Estimation will permit a new way of using cursors under conditions of induced impairment. Studying the properties of these algorithms interacting with specific induced impairments will extend the available academic knowledge about HIID or SIID motion-impaired user interaction with computers and furthermore develop new methods for making computer use more accessible. This potentially could be a bolt-on addition to existing GUIs, and guidance for user-interface development kits, so will be directly usable.

If successful, software based cursor analysis will benefit those whose motion-impairments inhibit the use of a keyboard and mouse for interacting with a computer. Those who already have limited access will benefit from easier computer access and those who are at present too severely impaired to use computers may be enabled to do so for the first time. This will provide them with an empowerment not previously experienced, from the ability to be more independent, to new vocational opportunities. It seems likely that users of diverse mobile computing equipment could benefit from the facility to selectively filter out unwanted effects of moving environments, for example, working on a train, without compromising system response. The results will also be applicable to users whose interaction is limited through natural ageing or deficiencies in the physical interface.

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