SINGLE-SWITCH NAVIGATION OF 3-D SPACES

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ABSTRACT

Low information capacity interfaces such as binary switches are often the only means by which some people with disabilities are able to interact with their environment. It has been long assumed that such interfaces can only enable the direct control of highly constrained binary activities. Based on this principle, single-switch, synchronous access techniques have been typically used to increase the scope of control (e.g. self-scanning menus). However, according to basic principles of information theory, it is also possible to take advantage of the more naturally asynchronous human-machine interactions in order to obtain increasingly accurate estimates of user intention. Furthermore, under optimal conditions, complex tasks such as navigation in dynamic 3-D spaces may be facilitated. In order to demonstrate this principle, we developed a transform that, when used in conjunction with recently developed algorithms for asynchronous single-switch access, may be used to enable navigation in 3-D spaces. Early tests in virtual environments have already demonstrated that single-switch navigation in 3-D dynamic environments is possible. However, additional research is needed in order to determine the full potential and limitations of such asynchronous approach to single-switch control.

INTRODUCTION

Binary switches are the simplest, most versatile and, therefore, most common interfaces available for people with disabilities. However, they are also the most limited in terms of information capacity since they can only code one discrete unit of information per activation. Therefore, it has been traditionally assumed that binary switches are naturally suitable for devices that present only two possible states and thus, can be controlled using only two commands (e.g. switching a light on or off). In order to enable single-switch control of devices that present more than two states, synchronous control strategies are typically implemented. These strategies use a timed protocol to compose additional messages. The Morse code, electronic serial communication, a computer's mouse double-click and self-scanning accessible menus are all examples of such timed (synchronous) protocols working on a single binary interface [1]. With synchronous protocols, each switch activation carries only part of a message. Thus, it is necessary to wait for a full packet of activations in order to compose a full command. In contrast, with asynchronous protocols, each switch activation carries a full message (e.g. “turn the light on” or “turn the light off”) and therefore, causes an immediate reaction in the device. Asynchronous interfaces are also more intuitive and accessible since the user does not have to learn the particular time-dependent protocol involved in synchronous strategies. However, the asynchronous expansion of binary switches for the control of devices with more than two possible states is not trivial, and in fact, to the best of our knowledge, it has never before been accomplished.

ASYNCHRONOUS SINGLE-SWITCH ACCESS

In order to allow for a binary switch to act in an asynchronous manner, the control strategy used must be able to assign to each of the two states of the switch an unambiguous message that may be immediately transmitted to the device.

Furthermore, following the principles of information theory [2], common messages should be coded with as few information units as possible in order to reduce the amount of effort invested by the user in controlling the device. This condition may be achieved if the user is required to interact with the device only when the latter is not behaving as he/she intends. In other words, if the user does not activate the interface, the device may assume that the message is “maintain your current behavior”. Accordingly, if the user's intentions change, it will be necessary to activate the switch. Under these conditions, there is only one possible unambiguous message that may be sent when the switch is activated, that is, “change your behavior”.

Given that the interface does not allow for any additional clarification, either the device itself or a previous decision module will be left with the task of discerning, among all possible behaviors, which one to select next. However, this selection process is far from uncertain and thus, may be optimized. In principle, the inverse probability of selection for the current device behavior must be one. In other words, we are at least absolutely sure that the user does not want the device to continue the current behavior. Furthermore, in cases where the control domain is represented by a numerical range where the Euclidean distance among similar behaviors is small when compared to that of opposite behaviors, it is also safe to assume, although with a lower level of confidence, that the user does not intend to select behaviors similar (i.e. close in Euclidean distance) to the current one. Figure 1 depicts a suitable statistical intention mask representing the above-mentioned assumptions.

Based on this theoretical analysis, Silva et al. (2006) [3] developed an algorithm that may be used to enable the selection of a particular element φ from a discrete one-dimensional domain θ, termed the intention space, using a binary switch. This algorithm is based on the deformation of a viscoelastic intention estimate $f(\theta)$ by means of an intention mask $g(\theta)$ according to the following relationship:

$$f(\theta)_{t+\Delta t} = f(\theta)_t + g(\theta)(1 - f(\theta)_t) \qquad (1)$$

Such deformation occurs every time the switch is activated and it is followed by a minimization that results in the selection of a particular element $\varphi \in \theta$:

$$\varphi = \arg\min f(\theta) \qquad (2)$$

It is important to note that any function $g(\theta)$ with compact support may be used as an intention mask. Thus, the intention mask itself represents the most important free parameter of the algorithm developed.

The intention estimate $f(\theta)$ is also modified by a time-dependent process according to the following equation:

$$f(\theta)_{t+\Delta t} = e^{-\Delta t / \tau} f(\theta)_t \qquad (3)$$

where τ is the viscoelastic constant of the user intention estimate $f(\theta)$. This viscoelastic process generates a “memory effect” that weights the influence of past deformations on the intention estimate $f(\theta)$ according to their age.

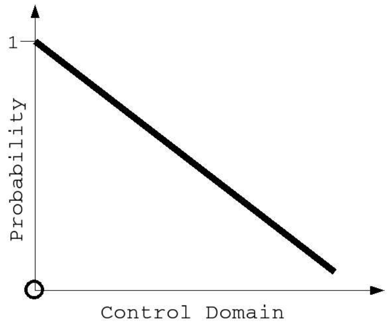

Figure 1: An intention mask of inverse probability of selection that may be used to aid in the selection of new device behaviors after an asynchronous switch activation. Only the current behavior (black circle) may be excluded with absolute certainty.

As demonstrated by Silva et al. (2006) [3], this algorithm may be used to generate non-parametric estimates of user intention $f(\theta)$ that not only respond immediately to the activation of a binary switch, but also incorporate historical data of previous asynchronous interactions to obtain increasingly accurate estimates of future intentions φ.

Silva et al. (2006) [3] adapted this process to the navigation of a virtual 2-D space by assigning a constant speed value to a virtual pointer and allowing the user to determine the angle φ of the pointer's velocity vector, using a binary switch in combination with the proposed algorithm. This task enabled single-switch 2-D trajectory tracking in a way analogous to the task of drawing. Thus, a single-switch drawing exercise was proposed to obviate the potential of the algorithm. However, the scope of the theory proposed extends well beyond a 2-D drawing exercise. In particular, it is possible to use the same algorithm to enable single-switch navigation of 3-D spaces.

3-D EXPANSION

In most cases, incorporating extra dimensions in numerical algorithms requires adjustments that increase the order of their time complexity. However, in the case of navigation, it is still possible to define higher dimensional behaviours without increasing the time complexity of the algorithm proposed. This is because for every behaviour (i.e. direction) chosen in a 3-D movement, there exists an opposite behaviour that may be obtained through a linear operation. In order to maintain time complexity, this linear operation must be defined as an offset on a one-dimensional domain. Thus, it is necessary to define a mathematical transform capable of mapping each one-dimensional asynchronous selection φ of the algorithm used for 2-D navigation, to a pair of numbers representing the longitude φ_a and latitude φ_l of the geographical coordinates of the 3-D velocity vector of a virtual pointer moving in space. Just as in the case of 2-D navigation, a constant speed value may be assigned to such vector to complete the definition of the behaviour. Figure 2 shows a graphical representation of a suitable transform. Such a transform represents a linear space curved around a sphere. Each position along this curve corresponds to values of longitude and latitude described by a vector pointing to the linear space from the centre of the sphere. This transform is also periodic; therefore, regardless of the direction and start position chosen, it is possible to arrive at the same place after covering a full period length on the curve. Furthermore, just as in the case of 2-D control, an offset of half a period length from any point in the curve, defines its exact opposite behaviour. Thus, the transform presented in Figure 2 may be used indistinctly with the algorithms already proposed, in order to extend the control process to a third dimension.

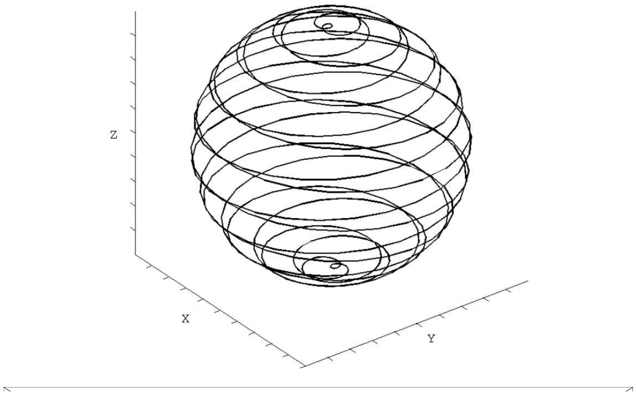

Figure 2: Graphical representation of a transform suitable for the expansion from 2- to 3-D control using the asynchronous control strategy proposed by Silva et al. (2006) [3].

The transform depicted in Figure 2 may be defined parametrically on each axis using a single angular variable φ:

$$\begin{aligned} z &= r\sin(\varphi), \\ x &= r\cos(\varphi)\sin(c\varphi), \\ y &= r\cos(\varphi)\cos(c\varphi) \end{aligned} \tag{4}$$

where r is the sphere radius and c is a constant that determines the number of cycles described by the curve around the sphere along its latitude. Furthermore, the equations that relate φ with the geographical latitude φ_a and longitude φ_l of the pointer’s 3-D velocity vector, turn out to be quite simple:

$$\begin{aligned} \varphi_a &= \varphi \\ \varphi_l &= c\varphi \end{aligned} \tag{5}$$

However, even though the relationships obtained from the proposed transform are trivial, it is important to note that in order to satisfy the offset conditions mentioned above (i.e. opposite behaviours must be half a period apart from each other), c must be an even integer.

FUTURE WORK

Future research on the development of real applications of the algorithms proposed here will focus on the implementation of a navigation task in a 3-D virtual space using the Blender™ modeling suite. This task will consist on using a single binary switch to drive a pointer to a specific target while avoiding a series of randomly placed, moving obstacles. A variety of single-switch users will be recruited in order to obtain important usability parameters. This study will be essential for the characterization and evaluation of the potential advantages and limitations of the algorithms proposed. Furthermore, once this characterization and evaluation stage is completed, we will move on to the implementation of control strategies for specific appliances in real settings with particular emphasis in robotic tools that may enable enhanced interactions between single-switch users and their environment.

ACKNOWLEDGEMENTS

We would like to acknowledge the financial support received from Bloorview Kids Rehab and the Health Care, Technology and Place interdisciplinary research program at the University of Toronto.

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