Physically accurate velocity distribution profiles for use in virtual reality training for prosthetic limbs

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ABSTRACT

Virtual reality has been used in many areas of application, from training to simulation. There is an increasing interest in using VR for training persons for prosthetic limb control. In a prosthesis, a myoelectric signal map to the velocity or position of a prosthetic joint. There is little evidence on what is the appropriate mapping between the myoelectric input and the prosthetic joint output. There is a possibility that a poor mapping will hinder the training. This study is the first stage in the process to understand this mapping, by studying the distribution of velocities in the intact arm in a conventional Fitts law test. What is observed is a wide range of velocities, decreasing in frequency as the velocity increases. This implies that for VR training to be effective a wide range of velocities need to be used in that training.

1. INTRODUCTION

Virtual reality has been used increasingly in many areas of application, from training to simulation. If it is used for training and is in the form of a game, it is important that the tool encourages the correct behaviours to ensure the subject is trained in a way that improves their performance, rather than increases their facility to play the game.

1.1 Control of prosthetic arms

Externally powered artificial arms use Electromyograms (EMGs) as control inputs, these are the electrical signals associated with muscle contraction (Muzumdar, 2004). They can be used to instruct a joint to flex or extend. The amplitude of the signal is mapped to a control signal in the prosthesis. This mapping is usually to the velocity of the motor (occasionally to joint position). Thus the velocity of the device and how it is controlled is an important factor when designing the control system, or simulating it for training. However little is known about the velocities used or what is the most appropriate mapping. While the relationship between muscle contraction and EMG amplitude is not precise, the user feels that the speed of the limb reflects the level of contraction of their commanding muscles. This control is not particularly natural and needs to be trained. Simple computer games have been employed for many years to train users of prosthetic limbs to control their artificial arm. To engage new users of prosthetic limbs, an aspect of play in the training is useful. Historically, the games written by the manufacturers of commercial prosthetics limbs have been extremely simple, low resolution and two dimensional, no more recent games have been written with the express purpose of training EMG control. With the increasing availability of high definition, fast action, computer games, these earlier tools increasingly look old fashioned and anecdotal experience in the clinics, show that they fail to engage modern users for very long. It is therefore useful to design games that engage the potential user more fully. However the task of matching the game to the needs of training have not been addressed. This study looks at a single aspect; the dynamics of the control input.

The question addressed is: *What should the mapping be between the contraction of the command muscle and the movement of the prosthesis?* If the motion is too slow, use may be tiring and frustrating and may result in the rejection of the prosthesis, but if the motions are too fast then the limb may be uncontrollable. If a VR is used to train the user and it has dynamics too different to that of the actual system it is conceivable that the user will have to unlearn their training before using the prosthesis well, and this too may cause them to reject the prosthesis. So being able to determine what simulation is sufficient to engender the correct response is an important part of the process of designing a training VR for prosthetic limbs.

Control of a prosthetic limb involves the placing the hand or fingers in the correct position to handle an object. The user is only interested in the simplicity of the control of the motion which is the combination of the speed of motion and the ease of control input. So it is important to know *how* the arm moves as it is used, that is, the *distribution of velocities* throughout the motion.

1.2 Velocity distribution in upper limb activities

A survey of the literature produced no objective evidence as to what are the distribution of velocities of natural limb motion in everyday life. Specifically, the literature focuses is on particular aspects of control, or the movements, positions or instantaneous velocities. Studies do not explicitly discuss the *range* of velocities a joint goes through for any specified task, simply peaks, profiles or angles (Bongers 2012, Andel 2008). Additionally no study has been made of the velocity distributions of proportionally controlled prosthetic limbs. Thus the purpose of this study is to understand natural kinematics of the human arm to allow comparison with the movement of a prosthesis in later studies. The starting point for this is the simplest task, to examine a simple pointing motion and observe the velocity distribution.

A model for human control is Fitts' law (Fitts 1954), this studies the way that a person will move between two points and is concerned with the trade off between speed and relative difficulty of the task. When the subject moves between two points they match the speed to the task. For points further away the subjects move faster, for targets harder to achieve (smaller) they slow the rate to ensure an increased level of precision. It has been used study a variety of applications; from operating a computer mouse, to measuring the use of pattern recognition of electromyograms in prosthesis control (Soukoreff 2004, Scheme 2014).

2. ANALYSIS OF VELOCITY DISTRIBUTION

2.1 Methods

2.1.1 Simulation. The implication of Fitts' law is that if a participant moves a limb (or part of a limb) between two points (for example a pointing task) their arm will accelerate to maximum speed for the majority of movement, to decelerate rapidly when the target is neared. So the distribution of velocities would have two peaks at low speeds and the maximum velocity (determined by distance and level of difficulty). This motion was simulated for a Fitts law test with a single difficulty Figure 1(a). Since it is the *distribution of the velocities* that is of interest in this study, the distribution was also calculated, Figure 1(b). The motion was a single symmetrical curve with 3000 time steps. The velocities are divided into 181 bins of size 0.006, and the number of instances counted across the movement. This result is for a single distance and single difficulty. However, the current study is concerned with motions in general activities, with varied distances, speeds and difficulties. This situation is simulated with performing the distribution analysis on five simulated motions, with the same distances to the target (Figure 2). This is then compared with data from an experiment on able bodied subjects.

2.1.2 Experimental data. Data was taken from an experiment designed to observe the use of upper limbs and was analysed to reveal the velocity distributions of the limb (Bongers 2009). Subjects used a tablet and moved a pointer between two points. Ethical approval for the original experiment, was received. Approval allowed the further use of anonymised data, only subject number, gender, age group (young or adult) and experimental group was used.

Each session began with a practice trial. There were six different distances and four levels of precision (difficulty), totalling 24 conditions, and ten subjects. For the purpose of this study, the velocity profiles for all conditions were analysed. The subjects were, five men and five women, ages 20 to 54. All participants were right-handed and had normal or corrected to normal vision. The movements were made with a stylus on a Wacom Ultrapad A3 graphics tablet (Wacom Company, Tokyo, Japan). Stylus movement was sampled at a frequency of 170 Hz. The movement times had six levels (200, 300, 600, 900, 1,200, and 1,500 ms) and four distances between the target lines (5, 10, 20, and 30 cm).

2.1.3 Data analysis. Position data of the pointer was inferred from the tablet. The velocity of the pointer was then mathematically differentiated to obtain the velocities of the pointer. The velocities were then divided into bins and the frequency of each bin counted and the results plotted, data was then pooled.

2.2 Results

2.2.1 Simulated data. Figure 1(a) shows the velocities of the simple motion of the pointer, the curve is bell shaped. Figure 1(b) shows the distribution, which is a bimodal curve with a peak at low speeds (close to stopped), and another peak at the maximum, with very few instances at other speeds, as was predicted.

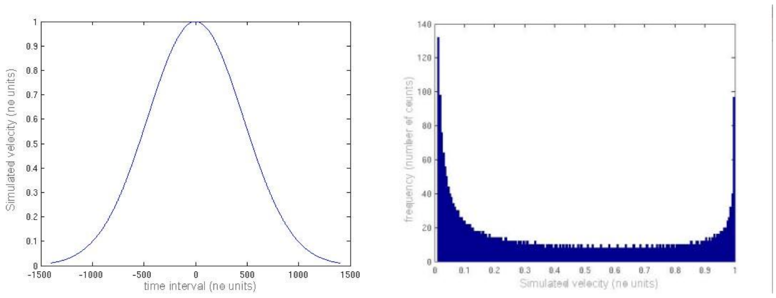

Figure 1. *(a) - Simulated velocity of a hand moving between two points in one plane. Velocity is normalised to a maximum of 1. (b) Velocity distribution of 1(a). The velocity is divided into bins of (181 bins) of size 0.006, instances of each velocity is then plotted.*

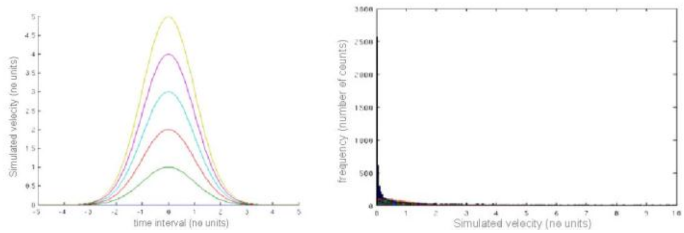

Figure 2. *(a) Range of velocities simulated, maximum velocities at integral values from 1 to 5.(b) Cumulative velocity distributions from 2(a). Bins are the same as 1(b). The distribution is now a single peak at zero velocity and a monotonic drop in higher velocities.*

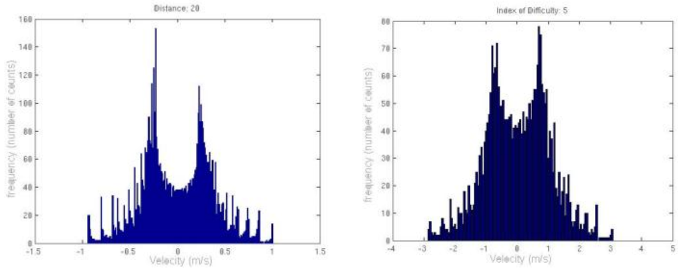

Figure 3. *Velocity distribution analysis of one inter-target distance (20cm) (Bin size 0.01) and one index of difficulty (5 for the Fitts' law experiment.*

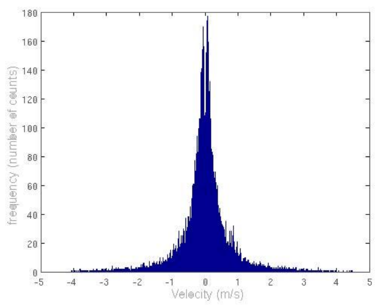

Figure 4. *Velocity distribution analysis all of the data from the Fitts' law experiment. What is revealed is peaks around zero velocity and a drop off as the recorded speeds increase. Bin size 0.001.*

Figure 2(a) shows the 5 different curves for different difficulties, i.e. that the subject would move more slowly as they became more careful to achieve the target. Figure 2(b), shows a curve with a single peak at zero and increasingly fewer instances of the higher velocities. If the test was conducted with motions in two directions (forward and back) then the curve would have a single peak at zero and monotonically falling off both in the positive and negative directions.

2.2.2 Experimental data. Figure 3 shows the velocity profiles for two of the instances of the experiment; each are one distance and one level of difficulty. The result is peaks at the maximum speeds (positive and negative) and fewer instances of intermediate speeds. For the original experiment; increasing distance resulted in increasing maximum speeds, and increased difficulty with reduced velocities. When the data from the entire experiment was pooled, with six distances and four levels of difficulty (24 groups), the bimodal nature disappears and a monotonic distribution becomes apparent, figure 4.

2.3 Discussion

Experiments to investigate the control of the natural limb are designed to isolate one aspect of human control for analysis. However, the regular use of the arm in daily activities is much less structured or closely confined. If prosthetic training is to reflect the real use of a prosthetic limb, then it must reflect the velocity distribution that the prosthetic arm experiences. For best control designers need to understand what compromises they make when they design a prosthesis system, this can only come from a position of knowledge. When designers and engineers are informally asked to reflect on what the distribution of velocities of a prosthetic arm during activities of daily living, they tend to predict a bell shaped curve; subjects accelerate to a maximum speed and continue until close to the target when they stop. From this it would seem that there is little consideration to the different speeds that might result from different tasks. It is likely that designers would tend to assume that there is little need to control the arm at speeds other than at maximum for transport and at slow speed, for close manoeuvring, but an arm controlled this way may be very hard to use. Thus as designers are not in a position to state what are the velocities used in natural manipulation and if the prosthesis controller (and hence training tool) needs a greater range of velocities. This analysis shows that the variations that underlie the Fitts law concept mean that over a range that reflects natural grasping is a different distribution, one where the frequency of the instance of a velocity decreases as the speed increases.

The next stage of this investigation will be to observe both unimpaired subjects and prosthesis users to determine if these finding reflect the velocity distribution in unconstrained tasks.

3. CONCLUSIONS

Motions over a wide range of distances and difficulties result in a distribution of velocities where there is decreased likelihood of a particular velocity as the speed increases. This implies that no velocity is more significant than any others. This suggests for a VR simulation for the purposes of training myoelectric prosthesis users, care should be given to the choice of the dynamics of the game.

4. REFERENCES

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