Elastic Control for Navigation Tasks on Pen-based Handheld Computers

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ABSTRACT

Isotonic pen and finger interfaces for handheld devices are very suitable for many interaction tasks (eg. pointing, drawing). However, they are not appropriate for rate controlled techniques, as required for other tasks such as navigation in 3D environments. In this paper, we investigate the influence of elastic feedback to enhance user performance in rate controlled interaction tasks. We conducted an experiment, which proves evidence that elastic feedback, given to input movements with the pen, provides better control for 3D travel tasks. Based on these findings, we designed several prototypes that illustrate the ease of applying various elastic control conditions to contemporary handheld computers with finger- or pen-based input capabilities.

Keywords: Design, Human factors, performance, experimentation, elastic control, mobile devices, 3D navigation.

Index Terms: H5.2 [Information interfaces and presentation]: User Interfaces—Input devices and strategies, Interaction styles;

1 INTRODUCTION

Handheld computing devices have shown many benefits as electronic companions. They enable the access of data such as text, images or web pages in mobile conditions and serve to store information like phone numbers or appointments. For such interaction, direct pointing with pen or fingers on the screen is the current standard input technique, similarly to the mouse in desktop configurations. Due to the congruency of haptic input space and graphical output space, the isotonic input that is based on the motion of a pen or fingers directly on the screen is very intuitive and effective. Interaction with mobile computer applications is therefore mostly discrete or position controlled. This is broadly accepted as working well for hypertext and menu interaction or scrolling through text and image documents.

Today, numerous new mobile computer applications are emerging. In particular, the hardware improvements of mobile devices favor the development of 3D applications. For many 3D interaction tasks, pen-based interaction may still be very powerful. For example, the co-location between the user's input action and the application's visual feedback allows for direct selection of 3D objects by picking their projections on the screen. For manipulation tasks, position controlled input with the pen to manipulate widgets is appropriate, since the motion space is relatively small. As a matter of fact, in manipulation tasks the rotations are cyclic while the translations are limited to the visible 3D space, that is naturally reduced on mobile devices.

On the other hand, fluid navigation in large 3D environments requires potentially infinite viewpoint motion. For tasks like these, position control techniques as currently provided with pen-based interaction are not very appropriate since they frequently require

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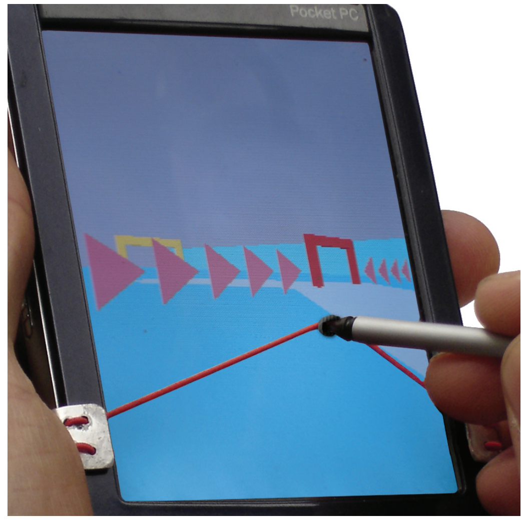


Figure 1: A simple rubber band adds elastic feedback to pen input on a PDA.

disturbing and irksome re-clutching. Rate control techniques seem to be more adequate. Zhai [15] demonstrated the superiority of elastic devices for rate control techniques regarding a 3D docking task. Following his findings, the isotonic resistance characteristic of the pen does not seem to be well suited for the rate control required in 3D navigation tasks. Consequently, we developed a simple concept to adapt the input characteristics of a handheld computer to benefit from an elastic feedback for the control of viewpoint trajectories (see Figure 1). Our approach may be applied to pen- or finger-based interaction devices in general. We present a comparative evaluation of elastic control versus isotonic control on mobile devices for a 3D travel task. We then present different approaches for further elaboration of the proposed concept. Finally, we conclude and point to directions in future work.

2 RELATED WORK

For viewpoint control in three-dimensional environments within the constraints of mobile handheld devices, Hachet et al. [7] presented an interaction technique that allows for discrete target selection, using the commonly available four direction keypads. Instead of selecting a travel destination on the x/y-screen plane, they propose to do so in the x/z-dimension of the 3D scene. To facilitate depth perception, the chosen range in depth is highlighted as a ribbon-like selection area covering the displayed environment. The travel movement however, is automated. Velocity along the trajectory may not be influenced by the user. Marsden and Tip [13] added a gyroscopic orientation sensor to a PDA and used the sensor for pointing gestures to choose travel directions with the handheld device. They compared the usability of a solely gesture based interaction, where also depth motion was controlled by tilting the device to a combination of the orientation sensor for motion direction and keystrokes for depth translation. The separated distribution of the two degrees of freedom showed superior performance. This is contradictory to Casiez et al. [4], who showed that DOF separation does not generally improve performance in 3D steering tasks. Thus, one might assess the lack of haptic feedback and self-centering to be a major reason for the difficulties in controlling movements with the isotonic input system of Marsden and Tip. Another approach to use hand gestures for controlling 3D travel movements, introduced by Hachet et al. [9], employs proprioception between both hands of the user. A camera attached to the mobile computer device held in the non-dominant hand, recognizes the motion of a tracking target, which is manipulated with the dominant hand. At least three degrees of freedom may easily be controlled this way, but since most interaction with contemporary mobile computers involves the dominant hand of the user to interact directly on the screen, this technique does not support frequent alteration between common interaction techniques and continuous 3D-motion input.

Buxton [3] proposed to regard the continuity of motor tension or motion closure as indicators of the cognitive structure of input commands. He argued that these kinaesthetic clues support the users perception of the respective input action as one integral (when performed within continuous tension or enclosed motion) or several following subtasks. He further suggested that an appropriate mapping of these input gesture characteristics to a meaningful structure of the interaction dialogue would reduce the cognitive load and facilitate the users acquisition of operational skills. In this regard, position control techniques do not seem to be appropriate for long distance travel tasks. Instead of covering the whole path with one enclosed input gesture, the task is divided into an array of subtasks, consisting of motion steps and reclutch actions. Hinckley [11] showed that in continuous 2D-navigation tasks, that rate control techniques are poor for reaching closely located targets, but that they become superior for controlling large distance motion. Andersen [1] furthermore demonstrated, that this is particularly true when the target position is not known and the user must search for it. He suggested that rate control facilitates searching, since it is easier with these techniques to maintain a constant velocity. Hence, large maps, three-dimensional environment simulations and many computer games are examples of applications where rate control techniques are required.

Evaluating user performance in a three-dimensional (6 DOF) docking task, Zhai [15] has shown that for rate control techniques, elastic sensors are superior to isotonic ones. Unfortunately, there is not much knowledge about these interdependencies regarding egocentric travel in 3D environments. Bowman et al. [2] developed a taxonomy of viewpoint control techniques for virtual environments and conducted experiments regarding the differences between gaze-directed and hand-directed selection of movement direction. They found ergonomic advantages for the hand-directed techniques, particularly since they allow for looking around while travelling. Comparing three different velocity/acceleration techniques, they furthermore showed, that continuous motion within the environment is essential to spatial awareness. While they did not find significant differences between constant velocity and a slow-in/slow-out condition, the resulting disorientation of an abrupt shortcut-like jump towards the destination (infinite velocity) becomes apparent in their results.

Mobile computer applications rely on different constraints than 3D environment simulations that are displayed on huge screens or HMD's. In that context, controller based interaction is mostly the preferable choice, because it does not require much space for interaction. This is not necessarily a disadvantage for information gathering tasks in environment simulations. Research by Suma et al. [14] and Interante et al.[12] indicate that controller-based travel techniques are not much worse than their more immersive counterparts using physical walking motion to explore three-dimensional environment simulations.

Recently Casiez et al. [5] suggested a strategy for adding elastic feedback to touchpad devices, that is similar to ours. By covering the touchpad with an elastic mask, they provide elastic feedback to its borders. They simulated such a device's behavior with a force-feedback device and studied issues of hybrid interaction techniques, consisting of position and rate control. Similar to [11] and [1], they also showed performance benefits for covering large distances when rate control is incorporated.

3 Elastic Control on Mobile Devices

Not only computer games, but also cartographic applications such as Google Earth already exploit the potential of three-dimensional environment visualization. Since they provide the possibility to explore landscape or city representations from a perspective that resembles the human perception of their real counterparts more closely, they are useful for route-planning tasks, that are preferably accomplished "on the road" with palm-sized mobile computers. Thus, well suited input systems to control first-person travel will become a necessary upgrade to handheld devices functionality. In the case of 3D-travel tasks, isotonic position control techniques cannot benefit from the input-output consistency, that makes pointer input directly on the screen so intuitive. There is no direct correlation of any input motion possible on the screen surface to the primarily required backward and forth motion, that is perpendicular to the viewing plane.

There are several ways to integrate elastic sensors for rate control into handheld computer devices. A certain number of those already offer two-dimensional joysticks to be controlled with the thumb, but in most cases, the touch sensitive screen is the only sensor offered for inducing continuous motion input. Touch sensitive devices are isotonic, and to facilitate precision within the small range of interaction, most of them are to be used with a stylus. This drawing-like interaction is very intuitive and precise. Furthermore it allows for various gesture based interactions (e.g. [10]) that are very efficient. Thus, we do not assume that elastic devices could replace the isotonic pen. Rather we propose frequent alternation between position control and rate control techniques, to achieve more fluent interaction.

Imagine for example the use of interactive three-dimensional city maps on mobile devices. Users would probably like to use the pen directly on the screen to select the general area of interest from a bird's-eye view. But to explore the chosen area more closely and to gather knowledge about its details, egocentric motion from a perspective that resembles human perception of environments is certainly more appropriate (Figure 2).

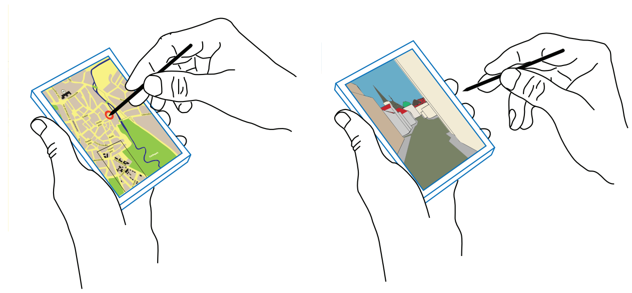


Figure 2: A route planning application should allow to interact with spatial data from a bird's eye view as well as from a street level perspective.

Driving a vehicle is the commonly chosen motion metaphor in those cases. It involves controlling back and forth motion in depth (z-translation) and orientation control (head-rotation) to adjust the direction of motion. As known from video game input devices, this kind of computer interaction may easily be accomplished with joystick-like elastic devices and is broadly accepted by users[12]. Unfortunately, such joystick-like devices are not very common among handheld computers. When existing, they can't actually be controlled with the pen, but only with the thumb. If not working two handed, this requires the user to put away the pen before using the elastic device. Note that in the case of handheld computers, the non-dominant hand is already involved in interaction to support the device. To improve that situation we propose to add elastic feedback directly to the pen on the screen with simple mechanical accessories. In contrast to embedded joysticks, this approach of covering touch sensitive sensor devices with an elastic feedback apparatus allows for high variability regarding the characteristics of the resulting elastic sensor system. We prototyped a set of possibilities using springs, rubber band and elastic fabric, which are discussed below. Combined with appropriate transfer functions, there is certainly a high potential of performance gain for specific applications. To prove the general usability of this approach and to examine its advantages, we decided to test the concept in its elementary characteristic and purely isotonic input in a comparative evaluation.

4 Evaluation

We evaluated the differences between isotonic and elastic controls for 3D trajectory tasks on mobile devices. We were interested in differences regarding the efficiency, accuracy and user preference in both conditions. The experimental setup for both conditions was exactly the same.

All the tested subjects were familiar with 3D applications but none of them reported much expertise with pen-based applications. All were university students, right-handed and aged between 20 and 27 years. Both evaluation tasks were performed while sitting with the computer device supported by their left and the pen operated with the right hand.

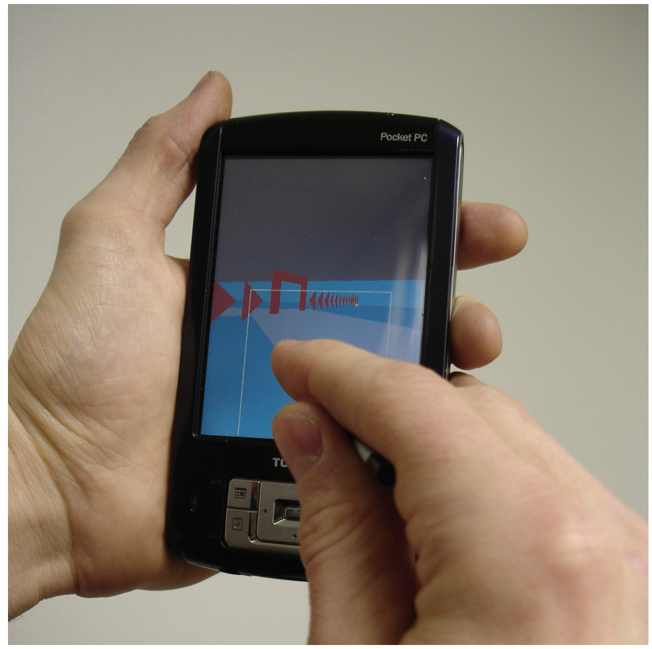
4.1 Experimental Setup

A PDA (Toshiba e800) with a 240×320 screen resolution was used for the experiments. The program based on OpenGL|ES and glut|ES was running at 23 fps, which is mostly perceived as realtime. A driving metaphor was used for the control of the camera trajectories, using left/right input motion for heading and up/down input motion to control forward/backward velocity. Thus, the movements of the pen in an *active area* controls the speed and the direction of viewpoint motions. We set the *active area* to a 200×200 pixels square. The center of the *active area* where the speed is zero is given by the pen's first starting point. The maximum speed is attained when the pen reaches the outline of the active area. The relation between pen deviation and velocity follows a linear transfer function. When the pen is lifted, the motion velocity becomes zero. The next display contact defines a new starting point. For user feedback, the *active area* is displayed on the screen (see Figure 3). To maintain a linear transfer function, the range of input naturally becomes reduced, when the user starts interaction close to the display's edges.

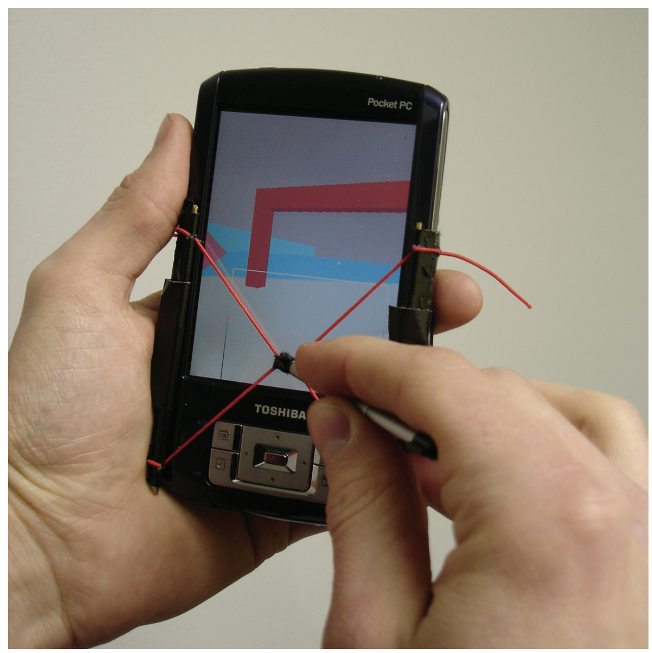
For the elastic mode, we used two elastic bands crossing the screen (see Figure 3(b)). This design is not optimal regarding visual ergonomics, but it ensures that the general settings of both conditions are close to equal.

4.2 Task

Much like a slalom competition, our evaluation task consists of passing gates located at different depths as fast as possible. During a run, the next gate to be reached is highlighted and arrows indicate its situation (see Figure 3). The arrows form a virtual wall, which is aligned to the current gate's depth. This wall cannot be crossed and each collision with the wall is recorded. Sliding along



(a) Isotonic feedback.



(b) Elastic feedback.

Figure 3: Experimental conditions. The white rectangle displays the interaction area. (Its center is dynamically positioned at the starting point of input induced with the pen.)

the wall consequently results in one collision for each frame. The next target to reach may be seen through this wall, since only triangular arrow shapes occlude the users view. Consequently, the subjects could anticipate their trajectories, which was intended and facilitated with training in front of each session.

After passing five gates the subject has to stop accurately at a sixth marked position. An accuracy value is set to *success* if the subject manages to stay in this area during one second once entered. Else, this value is set to *failure*. The completion time is measured between the first and the last gate before the stopping/parking area. Moreover, for each trial, we record the total distance of the subject's trajectory (length + cumulated rotations). Finally, the movements of the pen on the screen are recorded for each subject. Moreover, we record the number of times that the pen is detached from the screen (e.g. for re-clutching).

4.3 Isotonic vs. Elastic Input

To assure that both conditions were tested with adequate control display gain setting, we adjusted them according to the results of a pretesting that was conducted with six subjects, all unfamiliar with the usage of pocket computers. Interestingly, with the isotonic condition we observed a relatively large range of suitable control-display gain factors (CD-gain). The subjects simply adapted the motion amplitude with the pen to control similar resulting motion velocities in the 3D environment. This allowed us to employ the same CD-gain settings for the isotonic as for the elastic condition.

4.3.1 Procedure.

16 subjects were recruited (12 males, 4 females). Half of them first used the isotonic control, while the other half started with the elastic control. They were asked to complete the task 5 times, with both interfaces. In order to motivate the subjects, we organized the evaluation as a competition. We informed the participants that the winner would be the one with the shortest completion time to reach the target destination at the end of the trajectory. Only trials, where they managed to get there with less than 10 collisions and stop accurately at the end of the trajectory were taken into account. Just before performing a recorded session of trials with each interface, subjects trained five times to navigate through the path. Thus, they acquired knowledge about the demanded trajectory and skills with the respective interface. After the experiment, the subjects were asked to answer a questionnaire.

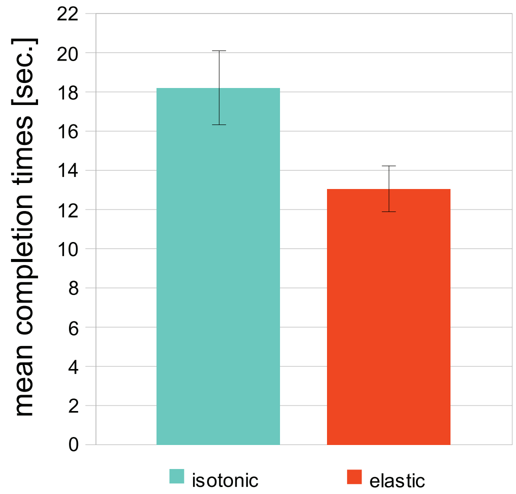
4.3.2 Results.

For each subject and for each interface, we computed the mean of the 5 completion times. We obtained one score per subject and per interface. We used the paired t-test to compare the means of the subjects' scores. We found that elastic control was significantly faster (28%) than isotonic control. The results are illustrated in Figure 4. Since the task was cognitively easy and subjects trained sufficiently in front of each test, we could not find learning effects in the recorded data.

We also found large differences between the two interfaces for the collisions. Since some subjects completed the task with only a few collisions while others extensively collided with the bounding walls of the implemented 3D scene, we recorded data with high variance. However, the impact of elastic feedback for reducing collisions is still significant. This result demonstrates an important gain of control with elastic feedback given to the user (Figure 5). Then again, we could not observe any statistical differences for the accurate stopping test, but this is not surprising, as the general strategy to stop viewpoint motion by detaching the pen from the screen, did not differ in either condition.

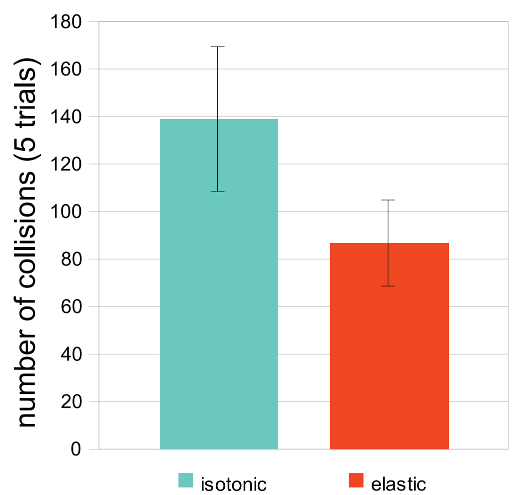
Concerning performed viewpoint motions, the elastic trajectories tend to be shorter than isotonic ones, but we did not find any statistical difference because of large standard deviations. The accumulated rotations, on the other hand, are statistically smaller when elastic control is used (isotonic mean$=893,81$ degrees, elastic mean$=647,44$ degrees, $t(15)=3.172$, $p=0.0063$).

Regarding the input continuity, it can be noticed that that subjects detached the pen from the screen, to stop and re-clutch more often with isotonic control than in the elastic condition (isotonic mean$=14,42$, elastic mean$=4,75$, $t(15)=3.832$, $p=0.0016$). Visually, this can be observed on the recorded input strokes of a representative subject (illustrated in Figure 6).



	Isotonic	Elastic
Completion time means (s)	18.21	13.05
Standard error	1.89	1.17
Significance	$t(15)=3.825$, $p=0.0016$	

Figure 4: Mean task completion times.



	Isotonic	Elastic
Nb. of collisions (means)	138.8	86.6
Standard error	30.5	18.08
Significance	$t(15)=2.484$, $p=0.0253$	

Figure 5: Average number of collisions per subject.

Among the 16 subjects, 14 reported that they preferred to use the elastic input technique. Only 2 preferred isotonic mode. More detailed user ratings are shown in Figure 7.

4.3.3 Discussion.

The results of our user study demonstrate several advantages of elastic over isotonic input devices to control viewpoint motion in three-dimensional environment simulations. This resembles findings of Zhai [15], even though our experimental conditions were very different from his. Zhai studied a 6 DOF object manipulation

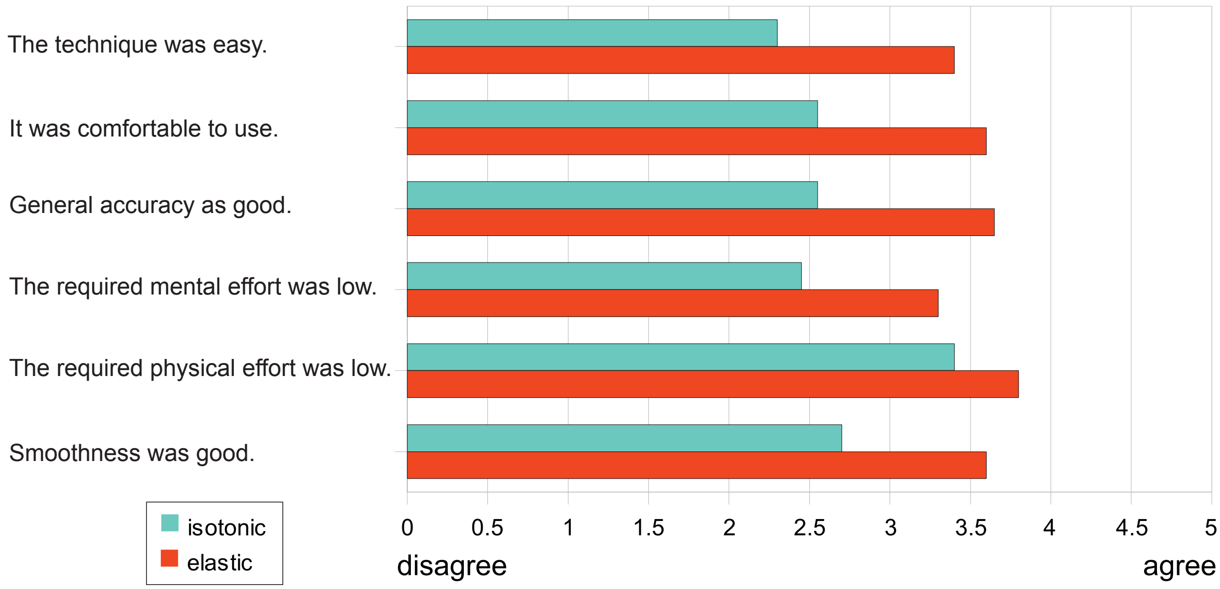


Figure 7: User ratings.

(a) Isotonic (b) Elastic

Figure 6: Example of pen movement during the experiment.

task, that demanded high precision. The isotonic device in his study was free floating without any support, while the elastic device was supported by a table. The test conditions differed in the following points:

1. We studied a viewpoint travel task, that involved only 2 DOF and did not required as much precision.
2. Despite the haptic feedback provided to the user in the elastic condition the general ergonomic parameters of both tested input systems were the same. In both cases, the pen as the actual interaction handle, was physically supported by the screen, to which it was applied.
3. The two-handed usage of the interaction system, provides proprioceptive feedback of the input motion to the user.

One could assume, that these differences may decrease the estimated performance benefit given by the the elastic feedback. Our results however, demonstrate, that a simple spring or elastic band mechanism, does result in better user performance regarding rapidity (lower task completion time), accuracy (lower number of collisions) and efficiency (less unnecessary motion). This is most certainly due to the haptic feedback, which gives the user a stronger perception of his actions, than solely the visual and proprioceptive feedback.

We further assume, that the elastic counterpoise reduces unintended motion as a result of hand tremor. The recorded differences of performed viewpoint motion indicate this, but the topic remains to be analyzed more closely. Following Buxton [3] each detachment of the pen from the screen divides the input gesture in separate chunks, because the applied motor tension changes and the motion continuity is interrupted. Supposing that this is true, our results show that isotonic input conditions for rate controlled travel lead to higher separation into subtasks and therefore to higher cognitive load to the user for the operation of the technique. Since the applied velocity gains for both conditions were the same, it can be assumed that the induced movement amplitude to control motion velocity are also similar. The larger interaction area for the isotonic condition, that can be seen in Figure 6, therefore illustrates the frequent displacement of the starting point for input actions.

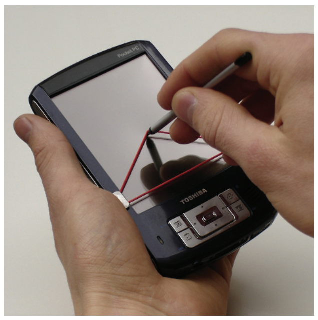
5 Elastic Insertions for the Pen

Figures 1 and 8 show examples of elastic insertion systems for the pen that we prototyped for informal experiments. Figure 1 illustrates a very simple insertion where elastic feedback is provided in any direction. One of the very interesting potentials is the combination of elastic and isotonic input characteristics for different degrees of freedom in one integral device (Figure 8(c) and 8(d)). Thus, rotational input could be mastered with isotonic position control, while translation is to be controlled with elastic rate control. Hachet [8] and Fröhlich [6] showed that those combinations are superior for certain tasks, especially for object manipulation within three spatial dimensions. Even different counterpoises may easily be issued to different degrees of freedom. Thus, just by the adaptation of the elastic input characteristics with different accessories and the transfer function by software, the same generic touch-sensitive computer device may comply to very different requirements of various tasks. Moreover, an appropriate accessory, may even facilitate one-handed usage with the thumb, if there is no elastic controller yet included (Figure 8(b)).

(a) Elastic pen insertion with small movement deviation.

(b) Elastic feedback system made of elastic fabric to be used with pen or thumb.

(c) Semi-elastic pen insertion, providing constrained isotonic input for one degree of freedom, while offering elastic feedback to the other.



(d) Semi-elastic pen insertion as in (c), but providing constraints to the elastic degree of freedom in relation to induced input with isotonic movement. High velocities may only be induced whilst rotational input is small.

Figure 8: Examples of elastic control insertion on PDA.

6 Conclusion and Future Work

We have demonstrated the ease of applying elastic feedback to touch sensitive devices with simple mechanical accessories. By evaluating these, we proved the advantages of elastic feedback for rate control techniques to displace the viewpoint in three-dimensional environment simulations, in particular for handheld computer devices. With elastic feedback, travel tasks can be undertaken faster, more accurately and more efficiently than without. To achieve more fluent interaction with complex computer applications that involve selection, manipulation and continuous navigation, we propose frequent alteration between the most adequate input techniques. Regarding the potentials and requirements of route planning applications on mobile devices, we therefore suggest using common position control techniques for coarse selection of the area of interest from a bird's-eye view and rate control techniques for their closer exploration from a first-person point of view. The implementation and evaluation of this general approach remains for future work. To favor fluent changes of both interaction techniques however, one should consider using the pen for both isotonic and elastic input actions, when integrating elastic feedback to pen based devices.

Following Buxtons [3] ideas about the cognitive structure of input actions, we further suggest, that rate control techniques induce a higher cognitive load, when operated with isotonic input sensors than with elastic ones. If this is true, differences in the ability to gather information about the explored environment should be observable. Proving this is a matter of our ongoing research.

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