Negative Inertia: A Dynamic Pointing Function

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Abstract

In-keyboard isometric joysticks can give better performance than mice for mixed typing/pointing tasks. The continuing challenge is to improve such devices to the point that they are preferable even for pure pointing tasks. Previous work has improved joystick performance by considering user perception and motor skills. This paper considers the dynamics of the pointing operation. A dynamic transfer function for an isometric joystick is described which amplifies changes in the applied force to increase responsiveness without loss of control. User tests show a 7.8 +/- 3.5% performance improvement over a standard non-dynamic joystick. This feature has been incorporated into the TrackPoint III from IBM.

Introduction

Because of the importance of pointing operations in the use of graphical user interfaces, much work has been done [1,4,6] to develop and compare devices such as mice, trackballs, and joysticks. Three major factors contribute to the performance of these devices: switching from typing to pointing, the pointing action, and switching from pointing to typing [2]. Compared to a mouse, the in-keyboard isometric joystick substantially reduces switching times, but with some penalty in pointing [4,6]. Both of these studies suggest that improved pointing devices could be designed by concentrating more on increasing pointing performance than reducing switching times.

Of particular interest is the transfer function, the mapping of control input into cursor motion. A mouse transfer function tends to be a simple physical mapping from mouse position to cursor position (though complexities such as "acceleration" are sometimes added). However, an isometric joystick transfer function maps applied force to cursor velocity. The best form of this relationship is not immediately obvious, giving rise to many possible transfer functions. Careful attention to the psychophysical details of the transfer function has resulted in substantially improved performance for the TrackPoint II [6]. This result shows that not all joysticks are equivalent and leaves open the possibility of continued performance improvements through further innovation in transfer function design. Most transfer functions depend only on the instantaneous input force, i.e. a certain control action results in a certain cursor motion independent of past control actions. Use of a dynamic transfer function, one which depends on past history, opens up new possibilities for enhancing pointing performance. Felsenstein [5] designed such a dynamic transfer function by adding smoothing filters which prevent rapid changes in cursor velocity. Our experiments have shown that this approach increases cursor sluggishness. However by designing a transfer function which amplifies changes in control action (an effect we call Negative Inertia), we have substantially improved pointing performance for isometric joysticks.

NEGATIVE INERTIA

The negative inertia concept comes from considering both the natural world and control theory. In the natural world, objects have inertia -- they require effort to get them going and effort to stop them. While there is no significant physical inertia in the isometric joystick system, there is a subjectively equivalent effect in the delay between the mental intention to change the applied force and the muscular response. The result is a perceived sluggishness and excessive user effort. This sluggishness can be overcome by amplifying changes, i.e. assuming that slight changes in control action indicate the user's intent for larger action. Negative inertia acts on the user's indications of intent, causing the cursor to respond with less effort.

We can model the pointing task as a closed-loop control system including the eye, hand, pointing device, and display. The transient response of a control system can be improved by adding dynamics. The most common approach is to add derivative control [3], i.e. respond to the rate-of-change of the control input. Negative inertia corresponds to additive derivative control.

FIGURE 1: The negative inertia transfer function

Figure 1 illustrates the effect of the negative inertia filter. The user applies an increasing force to begin a motion, holds constant while cruising, and then reduces the force to stop. The filter causes the motion to start and stop more rapidly while not changing the cruising rate. The velocity may actually become negative at the end of the motion causing the cursor to "back up" slightly. This response causes the cursor to be more responsive without loss of control.

DEVELOPMENT AND TESTING

Negative inertia was incorporated into an existing IBM TrackPoint II in-keyboard isometric joystick for testing. We had to consider many different implementation details, such as: should negative inertia be applied to the vector force or only to its magnitude? Should a running average or instantaneous values be used, and with what time constant and gain? Should it depend only on the rate-of- change or should the magnitude of the force be a factor? Should it be applied to the control force or to the cursor velocity?

We could imagine various answers to these and other questions, so iterative user testing became a necessary aspect of the development process. Our testing cycle had three stages: testing by team members at one site, by team members at another site, and then with users. We found that problematic features that were overlooked by the people writing the code were recognized quickly by team members at the other site, especially since the different sites had different biases for the subjectively optimal experience. After an implementation appeared good at both sites, we began testing with users. This methodology allowed us to try many different variations quickly and to avoid wasting time in unnecessary user tests.

These tests answered many questions which were surprisingly important for obtaining improved performance and subjective experience. For example, applying the negative inertia filter to the vector velocity produced a subtle, but irritating, weaving effect. As the direction of the force on the joystick varied either consciously or unconsciously, the negative inertia would amplify this change and make the cursor move in a slightly different direction than the instantaneous force on the joystick. Thus the cursor would "fish-tail" slightly along its course. We changed the implementation to apply the filter to just the magnitude of the motion. We also observed that what was intended to be a small, quick motion would often result in a jump which was much larger than expected. We solved this problem by using a non-linear gain in the negative inertia to reduce its effect when moving at low speeds.

Our best implementation of negative inertia was tested on a set of 16 subjects. The performance of 9 of these subjects was measured quantitatively and the subjective responses of all 16 were recorded. In the quantitative tests, subjects did a series of selections with the cursor, moving random distances between uniformly-sized targets. Several cycles of switching between the normal TrackPoint II transfer function and the negative inertia version familiarized the users with the test and were used to verify the results. Four users were tested with larger targets (size = 5 mm, average index of difficulty = 4) and five with smaller targets (size = 3 mm, average index of difficulty = 4.6). All nine subjects showed improvement with negative inertia. The larger target set showed a run-time improvement of 5.0 +/- 1.2%. The smaller target set showed an improvement of 9.4 +/- 3.4%. These results are significant with $p < 0.005$. Subjective preferences were recorded for all of the subjects. Ten of the 16 preferred negative inertia, 5 indicated no preference, and 1 preferred the standard transfer function. This result is significant with $p < 0.005$. The five with no preference were predominantly "low performance" users who either moved very slowly or were erratic enough to not notice the difference. Only one claimed to notice a difference but not have an opinion. The one user who disliked negative inertia was extremely erratic and operated the device by tapping on it rather than using smooth forces. The amplification of change made the unsteady motions even more random resulting in a negative opinion. Descriptive reasons given for preferring negative inertia were very consistent: "more responsive", "stops faster", and "less overshoot". Several claimed that the gain was higher for the negative inertia model so that it required less force to move and was less fatiguing to the finger, though the gain was actually the same.

CONCLUSIONS

We observe consistently improved pointing performance with an isometric joystick using a negative inertia transfer function. We measure the improvement over all our tests to be 7.8 +/- 3.5% for pure pointing tasks, with the greater improvements for higher-difficulty targets such as character selection. This improvement should be compared with tests showing early versions of TrackPoint II to be only 20% slower than a mouse for pure pointing tasks [6]. Unpublished tests of more recent versions of TrackPoint II have shown that its performance can be within 5% of a mouse for experienced users. Negative inertia, as a continuation of our work to optimize the user-device match, is a first step of incorporating dynamics into the transfer function. The importance of subtle details of the transfer function indicates that careful attention to perception-motor limitations will produce more improvements. Further study of dynamic transfer functions and representing the pointing problem as a closed-loop control system should continue to improve pointing performance.

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