Target Reverse Crossing – A Selection Method for Camera-Based Mouse-replacement Systems

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ABSTRACT
We propose a selection method, "target reverse crossing," for use with camera-based mouse-replacement for people with motion impairments. We assessed the method by comparing it to the selection mechanism "dwell-time clicking," which is widely used by camera-based mouse-replacement systems. Our results show that target reverse crossing is more efficient than dwell-time clicking, while its one-time success accuracy is lower. We found that target directions have effects on the accuracy of reverse crossing. We also show that increasing the target size improves the performance of reverse crossing significantly, which provides future interface design implications for this selection method.

Categories and Subject Descriptors
H.1.2 [**Models and principles**]: User/Machine Systems – *Human factors*; H.5.2 [**Models and principles**]: User Interfaces – *Evaluation/methodology*; K.4.2 [**Computers and Society**]: Social Issues – *Assistive technologies for persons with disabilities*.

General Terms
User Interfaces, Experimentation, Human Factors.

Keywords
Reverse crossing, camera-based system interface, mouse replacement system, assistive technology, interaction techniques.

1. INTRODUCTION
Individuals with severe motion impairments have the need to use computers but may not be able to control a mouse or work with a keyboard. If the motion impairment resulted from advanced neurological disease, such as amyotrophic lateral or multiple sclerosis, they may also not able to use a speech-recognition system as an input interface. A camera-based mouse replacement system can then be a valuable alternative [2,8,12,15]. Camera-based mouse replacement systems provide non-contact interfaces for non-verbal interaction that requires to the user to perform small motions with a body part that they can control, usually the head, sometimes a finger or foot. The Camera Mouse [2] is such a computer-vision interface system. It tracks the movements of a user and translates them into the movements of the mouse pointer on the screen. The Camera Mouse can be freely downloaded at http://www.camera mouse.org [3] and is widely used by people with motion impairments in homes, schools, and hospitals.

Most camera-based mouse replacement systems, including the Camera Mouse, use *dwell time* to select a target on the screen: Maintaining the pointer in the target region for a certain period of time issues a left-click selection command. Users with motion limitations may have difficulties with dwell-time selection during the corrective phase (pointing consists of a ballistic and a corrective phase [11]) for various reasons. The user may have trouble holding still. The pointer may slightly move while the computer-vision system is trying to recognize the user's body part. The target region may be too small.

The *goal-crossing selection* mechanism was proposed by Accot and Zhai [1] as an alternative selection mechanism. With goal crossing, the user selects an object by crossing the boundary of a target. Wobbrock et al. [16, 17] showed that goal crossing created smoother target acquisition movements for people with motor impairments who used the regular mouse than regular pointing. Other *enhanced area cursors* are also noteworthy, such as *bubble cursors* and *magnification cursors*, which were designed to help people with motion impairments acquire targets using the regular mouse [7, 9].

Previous research focused mostly on interaction design for regular mouse pointing. Works about new and enhanced interaction designs for camera-based mouse replacement systems are rare. This paper describes the design of a selection method, *target reverse crossing*, which was inspired by goal crossing. Target reverse crossing requires the user to control the mouse pointer by first entering the target region and then leaving it by crossing a certain target edge. Reverse crossing may be a helpful replacement of the dwell-time selection mechanism for camera-based mouse replacement systems. It avoids the possibly difficult-to-fulfill requirement that the user must control the pointer in the target region for a certain time.

To evaluate the performance of the reverse-crossing and dwell-time selection methods using the Camera Mouse, we designed a selection task experiment. Based on our statistical analysis of performance measurements and feedback from users, we found that target reverse crossing is a useful selection mechanism that may replace dwell-time clicking. We also found that the target size and direction are important factors when designing the user interface for a camera-based mouse-replacement system.

2. EXPERIMENT
2.1 Participants
Ten able-bodied adults, four females and six males, with an average age of 26 years volunteered to participate in the

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experiments. All participants could move their head freely. Half of them had little previous experience using the Camera Mouse.

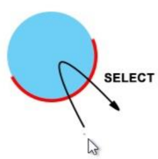
2.2 Apparatus

The experiment was conducted on a PC with an Intel Xeon® 2.67 GHz CPU, 12 GB RAM, running Windows™ 7, and a 30-inch LCD monitor (2,560 ×1,600 pixels). We used the Camera Mouse 2013 [3] software as the video-based mouse-replacement input system. The real-time video input source for the Camera Mouse was captured by a Logitech QuickCam® Pro 9000 webcam (8 megapixels).

2.3 Design and Procedure

Detailed descriptions of dwell-time clicking and target reverse crossing and their graphical interfaces are given in Table 1.

Table 1. Description of two selection methods

Name	Selection	Description
Reverse crossing		When the cursor crosses the edge of the blue target, a red semicircle, bisected by the entering point, appears. If the cursor reverses direction and moves out of the target through this red edge, a selection is made.
Dwell time		When the cursor dwells somewhere on the blue target for a certain period of time, a selection is made.

Every participant was asked to perform in two sections, 5 reverse-crossing and 5 dwell-time experimental blocks, resulting in 10 subsequent blocks. To reduce the learning range effect [14], we balanced the order of the reverse-crossing and dwell-time sections. In each block, a blue circle with one of three sizes (radius = 35, 50, 65 pixels) in one of 8 possible positions (showed in Figure 1) was displayed on the screen. For each block, all 24 (3×8) possible settings were displayed once in a random order.

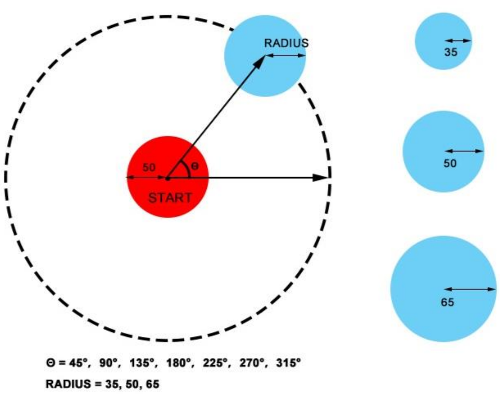


Figure 1. Experiment Interface

The red button in the center of the interface is the start button for a trial. After the cursor dwells on it, it disappears and a blue disk (target) appears with one of the 24 possible settings. In the reverse crossing experimental block, the participant was asked to conduct a reverse crossing selection of the blue circle, while in the dwell-time block, the participant was asked to move the cursor to the target and stay at least for 1 second (dwell time).No matter whether a participant selected the target successfully or missed it, the experimental system always stored the result and began the subsequent trial. We set a time-out limit for each trial. The maximum time allowed for one trial was 10 s; after 10 s, the current trial was marked as a time-out and would be discounted in the analysis of the results.

2.4 Metrics

We measured movement time and accuracy for both dwell-time clicking and target reverse crossing. Movement times of the ballistic and corrective phases were measured separately as well.

2.4.1 Movement Time

All time metrics were calculated using the mean time of trails.

Ballistic Phase Movement Time (BMT). The BMT was measured from the point in time when a trial was activated (the start button has been clicked) to the point in time when the cursor entered the target for the first time.

Corrective Phase Movement Time (CMT). The CMT was measured as the period between the end of the ballistic phase and the selection of the target. The corrective phase can be difficult for a camera-based mouse-replacement system since the instability of the cursor is hard to avoid completely. Thus, this metric is important for evaluating target selection methods.

Total Movement Time (TMT). The TMT is the sum of the BMT and CMT. This metric has been used in many pointing and goal-crossing user-interface experiments [1, 7, 16, 17].

2.4.2 Accuracy

Accuracy for this experiment was defined as the percentage of correctly selected targets. The definition of "missing a target" (incorrect selection of a target) for the dwell-time method was "dwelling outside the target area," and for the reverse-crossing method "leaving the target by crossing over the non-highlighted edge" (Figure 2).

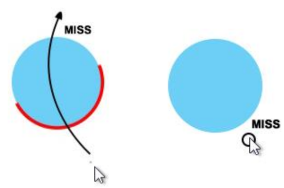


Figure 2. Target miss: reverse crossing (left) and dwell-time (right)

3. RESULTS

Our experiment generated 2,400 records. We used the "repeated measures analysis of variance" (rANOVA) to analyze our data for the different target selection methods, experiment blocks, and target sizes. We used a pairwise comparison when analyzing the effects of learning and target size (significance at $p < 0.05$). For evaluating the effects of target direction, we used the mean of the TMT and accuracy metrics to illustrate the effects of direction on different selection methods.

3.1 Movement Time

We found a significant difference in the TMT between dwell-time and reverse crossing ($F_{1,18}$=111.06, p<0.00001). The time measurement for dwell-time method included the 1 s dwell time, which could be reduced but not be avoided.

The measured significance level ($F_{1,18}$=872.5, p<0.00001) showed that the selection methods affected the corrective phase. Reverse crossing saved about 0.6 s in this phase because it did not require the subject to keep the cursor in a target region for a

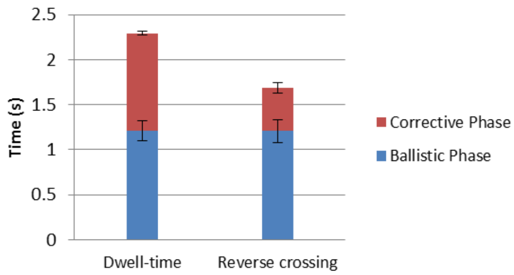


Figure 3. Reverse crossing reduced CMT and therefore TMT.

certain time. We did not find a significant difference in the BMT between the two methods ($F_{1,18}$=0.01, p=0.9133) (Figure 3).

3.2 Accuracy

The difference in accuracy between the two methods was significant ($F_{1,18}$=66.04, p<0.00001). The average accuracy was 96.7% for dwell time and 79.3% for reverse crossing. This can be explained by the fact that we counted crossing out of the non-highlighted part of the boundary as a missed selection, which apparently occurred frequently. The accuracy measured by this experiment was the accuracy of a **one-time** successful selection. In an actual application of reverse crossing, if the cursor slipped out of the non-highlighted boundary by mistake, the user can go back and reapply reverse crossing and thus avoid an error.

3.3 Learning

The learning effects for both methods were weak in our experiment. No significant difference between blocks was found for the dwell-time method in both TMT ($F_{4,45}$=0.78, p=0.542) and accuracy ($F_{4,45}$=1.09, p=0.3745) metrics. No significant difference was found for reverse-crossing in TMT ($F_{4,45}$=0.71, p=0.5912) and accuracy ($F_{4,45}$=1.58, p=0.1962) metrics as well. Pairwise comparison did not show any significance (Fig. 4).

Since none of the subjects had used reverse crossing, the results show that this selection method could be learned naturally without training. Some of the subjects had experience with the Camera Mouse and dwell-time clicking, so that may have been a learning effect. However, Feng et al. [5] found for previous experiments with the Camera Mouse and the dwell-time selection that the learning effects were not significant.

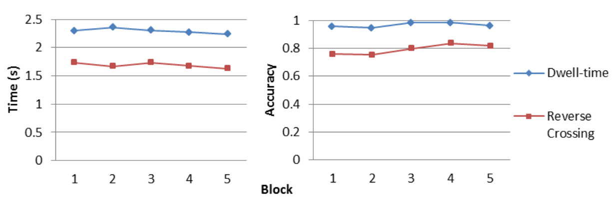


Figure 4. The learning effects of both methods are not significant.

3.4 Effects of Target Size

Different target sizes significantly affected both accuracy ($F_{2,27}$=28.04, p<0.00001) and movement time in reverse crossing ($F_{2,27}$=4.04, p=0.0292). A pairwise comparison showed that the increase of size can apparently improve accuracy. Figure 5 reveals that the effects of size on accuracy is likely reduced when the target radius is sufficiently large. For dwell time selection, target size also mattered ($F_{2,27}$=7.1, p=0.0033). There was no significance found for movement time ($F_{2,27}$=2.57, p=0.0955). However, Figure 5 shows that the average movement time had the trend of becoming shorter when the target size was increasing.

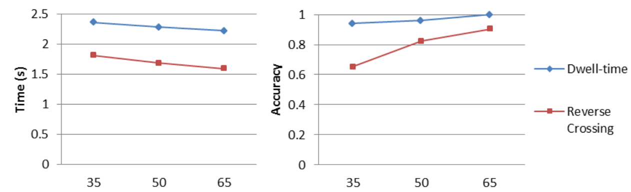


Figure 5. A larger target size improves the performance of both dwell-time clicking and target reverse crossing.

3.5 Effects of Target Direction

Due to the volume of data per subject, we did not perform a statistical analysis of the effects of target direction. However, based on the whole data set, we found target directions were likely influencing the accuracy of target reverse crossing. The straight up, down, right and left directions had lower accuracy than the four diagonal directions (Fig. 6). A possible explanation of this phenomenon is that ergonomic factors affect the mouse-replacement system interface performance to some degree, i.e., controlling their diagonal head movements may have been easier for some subjects.

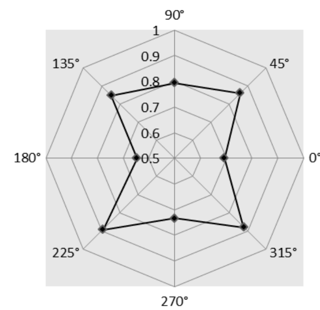


Figure 6. The target directions influenced the accuracy when using reverse crossing.

3.6 Subjective Feedback

3.6.1 Preference

After the experiment, we asked the participants to choose the selection method they preferred and explain their choice. Half of the subjects preferred target reverse crossing while the other half chose the regular dwell-time clicking. Subjects who preferred reverse crossing felt that it is the more efficient selection method. One participant who preferred the other method said *"Dwell-time clicking is more natural."*

3.6.2 Fatigue

None of the participants appeared to become fatigued during the experiments. However, two of the subjects said keeping the cursor in a target region made them feel tired after several blocks of dwell-time selection. Three of the participants said they were afraid of missing targets when using reverse crossing, and this made them feel somewhat nervous.

4. DISCUSSIONS AND CONCLUSIONS

Target reverse crossing, the method we evaluated in this paper, had a satisfactory performance when used with a camera-based mouse-replacement system. Both statistical analysis and subjective measurements showed that reverse crossing was more efficient than regular dwell-time clicking. Whereas, we found that accuracy of reverse crossing (one-time success) was lower than dwell-time selection. A possible way to solve this problem is to enlarge the target size or magnify the target using an enhanced cursor.

Dwell-time selection is commonly used not only by camera-based mouse-replacement systems but also by other assistive systems, for example, that are based on gaze tracking. Some participants felt dwell time is a natural and easy selection mechanism. However, when considering the speed of the selection process, it must be noted that the dwell time itself increases the movement time during the corrective phase of selecting a target. In addition, maintaining a cursor that is not as stable as a regular mouse pointer in the target region for the dwell period might cause fatigue in the long term.

Our experiment also evaluated the potential learning effects for both selection methods. We found no significant differences between experiment blocks and conclude that both dwell time and target reverse crossing are intuitive selection methods that computer users without disabilities learn to use immediately.

We found that target size could significantly affect accuracy and movement time of reverse crossing, and influence the performance of dwell-time clicking to some degrees. Target direction was also a factor that affected the accuracy of the performance of reverse crossing. Thus, in the design of a graphic interface for a camera-based mouse-replacement system, one needs to take target size and target direction into consideration.

5. FUTURE WORK

The experiment we conducted produced some inspiring results. We need to do additional experiments and collect more data to discover the relationship between the performance of a selection method and target direction. We could also refer to ergonomics research and 2D Fitts' Law for developing a theoretical foundation. We will extend our research with more selection methods. Enhanced cursors, for example, the bubble cursor [9] and the area cursor [6], will also be tested with the mouse–replacement systems.

To better understand the need of people with motion impairments, we will include participants with disabilities in our future research about interface design and interaction tools for camera-based mouse-replacement systems. A human-focused research methodology that uses interviews is also important. We will improve the Camera Mouse, which includes, but is not limited to (1) use of kernels as the tracking mechanism to improve the tracking [4], (2) design of an interface that involves other input methods such as blinking [12] or eyebrow raising [10], and (3) addition of functions like select and drag to improve the usability of the Camera Mouse.

6. ACKNOWLEDGMENTS

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