Exploring The Adaptive Bubble Cursor In Gamified Environments

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ABSTRACT

This study investigates the performance of the Adaptive Bubble Cursor in a dynamic environment. The cursor dynamically resizes its activation area based on the proximity, density, and motion of the target, thereby improving speed and accuracy of selection. Moreover, the design incorporates gamified features such as streaks, levels, and real-time audio feedback to boost user engagement. This research compares the Adaptive Bubble Cursor with the Traditional Point Cursor through a series of experiments that evaluate movement time, accuracy, and user engagement. Results show that the Adaptive Bubble cursor significantly outperforms the Traditional Point Cursor in both stationary and moving targets, and especially in high target density. These findings offer valuable insight into efficient and adaptive pointing applications.

1 INTRODUCTION

Cursor interactions are the very basis of human-computer interaction, acting as a bridge between users and graphical user interfaces (GUIs). Traditional Point Cursors often present limitations, particularly in dense layouts, such as gaming or professional design software, through longer target selection times and higher error rates. These limitations can reduce productivity and impede user experience, primarily in tasks that require precision.

To address these challenges, the foundational Bubble Cursor introduced dynamic resizing of its activation area, to adapt to the cursor's closest target. While this innovation improved target selection in static or stationary environments, its use in fast, motion-heavy and high-density scenarios remains under explored. This study investigates our Adaptive Bubble Cursor instead, which builds upon the original Bubble Cursor; integrating context-aware adaptability, improved algorithms for dynamic environments, and gamified features. This combination proves advantageous, with better target acquisition in dense, dynamic scenarios, as well as sustained user engagement through real-time, interactive feedback.

Thus, this experiment explores the performance of our Adaptive Bubble Cursor versus the traditional Point Cursor. Our research aims to answer three key questions:

(1) Does the Adaptive Bubble Cursor improve target acquisition speed in dense layouts? (2) How well does it perform in dynamic and static target environments? (3) Can gamification elements (streak counters, levels, feedback sounds, backgrounds) increase user engagement and satisfaction?

By answering these questions, we add to the small but growing body of existing literature on adaptive interfaces and provide actionable insight on how to design effective pointing mechanisms.

2 TECHNIQUES

2.1 Adaptive Bubble Cursor Design

The Adaptive Bubble Cursor extends on the basic Bubble Cursor concept by adding dynamic, context-aware features that enhance its usability in high-density and dynamic environments. While the original Bubble Cursor dynamically resized its activation area to prioritize the closest target, our Adaptive Bubble Cursor extends this functionality by incorporating additional adaptability based on the surrounding environment, target behavior, and user interaction patterns. Key features include:

2.2 Dynamic Resizing Based on Context

The Adaptive Bubble Cursor not only adjusts its activation area based on the proximity of the nearest target but also considers contextual factors such as target density, motion speed, and size. For example, in environments where multiple targets are moving, the cursor dynamically adjusts and renormalizes its focus area to help you select the right target more efficiently. It prioritizes targets moving along your intended path, making it easier to stay accurate even in fast-paced or complex situations.

2.3 Proactive Visual Feedback

Advanced mechanisms of visual feedback allow users to enhance interactions with targets more effectively:

- **Target Highlighting:** Targets within the activation area are highlighted with a glowing effect, providing immediate visual cues for selection readiness.
- **Cursor Transitions:** The cursor shows subtle visual transitions, such as changes in size, opacity, and colour, based on changes in its activation area. This feature helps during dynamic scenarios where targets could be in motion or overlapping, offering real-time feedback.

2.4 Gamified Engagement Mechanisms

The Adaptive Bubble Cursor integrates gamification features to improve user motivation and engagement during tasks:

- **Streak Counters:** Consecutive successful target selections are rewarded with a streak counter, where levels get harder based on successive streaks, facilitating an engaging and dynamic environment and motivating consistent performance from users.
- **Level Counters:** Levels are prominently visible throughout the game to engage the users and create a gamified experience for them.
- **Dynamic Challenges:** As users achieve higher streaks or levels, the system introduces difficulty variations, such as smaller targets or increased target movement speed and randomness.
- **Real-Time Feedback:** Both visual and auditory cues are provided for successful selections (positive chime sounds consistent with current games) and missed attempts (subtle error tone consistent with errs), making the interaction experience immersive and rewarding.
- **Progressive Backgrounds:** Backgrounds are used throughout the game, with increasing distractors in muted colors

to add subtle elements of difficulty. This improves user engagement due to the visual enhancements and maintains an element of surprise across various levels of the study.

2.5 Adaptive Behavior for Target Movement

The cursor intelligently predicts target behaviour in dynamic scenarios. For instance:

- In levels where multiple targets are moving simultaneously, the cursor prioritizes the trajectory of slower-moving and closer targets to reduce selection errors.
- The activation area dynamically adjusts to ensure the nearest viable target is always within reach, even if targets are rapidly changing positions in levels where target motion speed is increased.

2.6 Advantages of the Adaptive Bubble Cursor

The Adaptive Bubble Cursor overcomes certain limitations of the original Bubble Cursor by improving performance in dynamic and high-density environments. This adaptive mechanism, depending on factors such as motion, density, and user interaction history, provides higher accuracy and effectiveness. Our approach of gamification within user selection practices further transforms these routine tasks into engaging experiences, increasing retention and satisfaction.

The Adaptive Bubble Cursor can find its applications in gaming environments with rich user interfaces and intricate layouts; productivity tools that require precise interactions; and accessibility-focused software where users can be at ease from cognitive and physical strains in target selection.

2.7 Implementation

The Adaptive Bubble Cursor was developed using Unity 2D due to its powerful handling of real-time interactivity and dynamic rendering. C# scripting was used to implement adaptive resizing of the cursor's activation area, which was calculated in milliseconds to allow for seamless real-time transitions across both static and dynamic environments. A custom algorithm was employed to prioritize targets with closer proximity and motion trajectory, ensuring constant recalibration of the cursor's focus in different scenarios.

The interface contains a grid of targets with a variety of densities, sizes and motion, simulating real-world scenarios such as densely populated user interfaces or moving objects. Accordingly, the cursor activates an area that automatically changes radius on its target proximity, density, and motion, ensuring only the nearest viable target can be selected to enable efficient and accurate target selection. For enhanced usability, the system incorporates real-time feedback through the following features:

- **Visual Aids:** Targets turn from red to green as they enter the activation area, thus giving immediate confirmation of readiness. The closest target within the activation range of the Adaptive Bubble Cursor turns yellow, and the cursor itself shrinks and shifts to blue, indicating accurate alignment of the cursor with the target.
- **Auditory Cues:** Positive auditory signals accompany successful selections, while subtle error tones indicate missed attempts, providing immediate, immersive feedback.

Gamification elements to incentivize users and maintain their interest in continuing were integrated throughout the game. These include streak counters and levelling up, dynamic difficulty adjustments, and level-based backgrounds where each level has a different background to create a progressively engaging experience from start to finish. Unity's flexible framework allowed for incorporation of this behaviour, its scalability enables future potential applications of the cursor in gaming, productivity, and accessibility software.

3 EXPERIMENT

3.1 Participants

A total of ten participants were recruited for the study, in which none of them had prior experience with the Adaptive Bubble Cursor. This recruitment strategy ensured a neutral baseline when assessing the performance and usability of the system. Each participant was exposed to a new background in each level of the game, in order to minimize learning effects across levels and sustain user engagement throughout the trials.

3.2 Procedure

A brief training session introduced participants to the two cursor types (Adaptive Bubble Cursor and Point Cursor), along with the two target conditions (static and dynamic/moving). Following this, participants completed randomized trials for each condition, during which metrics such as Movement Time (MT), accuracy and engagement were tracked and logged automatically via Unity. In particular, all interactions (from target selections to streaks achieved) were automatically recorded for post-processing analysis.

3.3 Measures

Performance was evaluated using the following metrics:

- **Movement Time (MT):** The time taken to successfully select a target, measured in seconds.
- **Accuracy:** The proportion of successful target selections relative to total attempts, representing precision.
- **Engagement:** Assessed through the number of streaks achieved during the trials and the participant feedback on motivation and enjoyment.

3.4 Experimental Design

The study used a within-subjects study design to control for individual differences among participants. The independent variables were:

- **Cursor Type:** Adaptive Bubble Cursor vs. traditional Point Cursor.
- **Target Density:** Low density (widely spaced targets) vs. high density (closely packed targets).
- **Moving Targets:** Stationary targets (0) vs. moving targets (1).

The dependent variables—movement time, accuracy, and engagement—were recorded and analyzed to evaluate the effectiveness of the Adaptive Bubble Cursor under varying conditions.

4 RESULTS

4.1 Performance Metrics

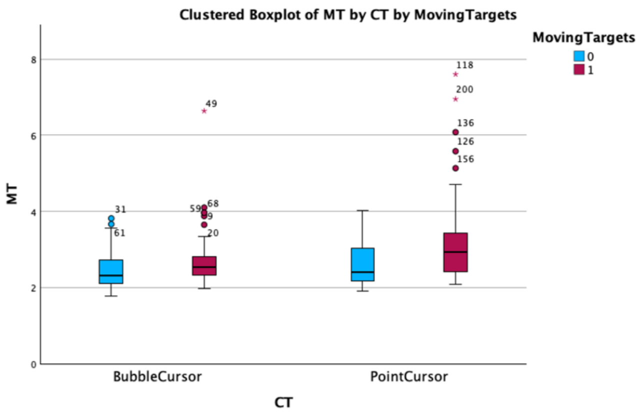

Figure 1: Clustered boxplot of Movement Time (MT) by cursor type (CT) and target motion conditions.

The Adaptive Bubble Cursor outperformed the Point Cursor across all conditions. Key findings include:

- **Mean MT:**
  - For static targets, the Bubble Cursor achieved a faster mean MT of 2.78 seconds compared to the Point Cursor at 3.15 seconds.
  - For dynamic targets, the Bubble Cursor recorded a mean MT of 2.77 seconds, while the Point Cursor showed a slower mean MT of 3.26 seconds.
- **Error Rate:** The Bubble Cursor significantly reduced errors, with an error rate of 8% compared to 15% for the Point Cursor.
- **Missed Clicks:**
  - For static targets, the Bubble Cursor had no missed clicks, however the Point Cursor recorded a mean of 0.02 missed clicks per trial.
  - For dynamic targets, the Bubble Cursor recorded a mean of 0.06 missed clicks, compared to a higher mean of 0.10 for the Point Cursor.
- **User Engagement:** Participants found the Bubble Cursor more intuitive and engaging, as reflected in higher streak counts and reduced error rates.

4.2 Statistical Analysis

Statistical tests validated the observed performance differences and provided deeper insights into the influence of cursor type and target density on movement time (MT):

- **T-Test:** A significant difference in MT was found between the Adaptive Bubble Cursor and the Point Cursor ($p = 0.009$). This result indicates that the Adaptive Bubble Cursor consistently enabled faster target acquisition, with the lower p-value confirming the robustness of this difference.
- **ANOVA:** The analysis of variance revealed that both cursor type ($p = 0.006$) and target density ($p < 0.001$) had significant effects on MT:
  - The Bubble Cursor consistently performed better, especially in high-density conditions, highlighting its adaptability in environments with closely spaced targets.
  - Increased target density also caused slower movement times for both cursor types, as expected in complex layouts requiring greater precision.
- **Interaction Effect:** A two-way ANOVA showed a significant statistical interaction between cursor type and target motion ({F}(1, 196) = 5.03, {p} = 0.027), suggesting that the performance gap between the cursors widened in dynamic environments.

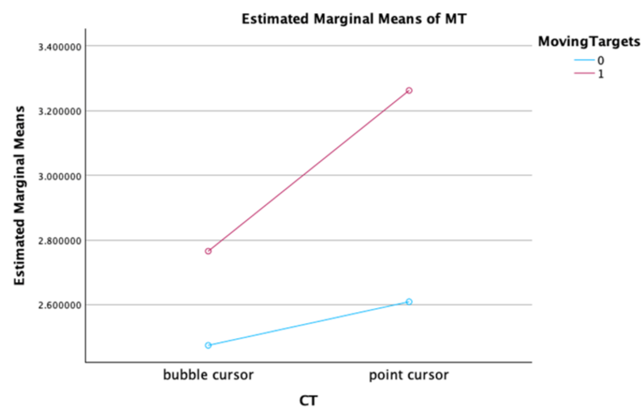

Figure 2: Estimated marginal means of Movement Time (MT) by cursor type (CT) and target motion. This chart illustrates the interaction effect observed in the study.

These statistical results showcase the Adaptive Bubble Cursor's durability in high-density scenarios where the Traditional Point Cursor struggled. The decrease in error rates (15% vs. 8%) display the effectiveness of its dynamic resizing component; in reducing both cognitive load and precision. In contrast, the increased MT in dense layouts align with the highly used principles of Fitts' Law, which states that increased target difficulty will necessitate finer motor reflexes.

5 DISCUSSION

The Adaptive Bubble Cursor shows significant improvement in target selection efficiency, particularly in dense and dynamic environments. The resizing mechanism of its activation area gets rid of ambiguity in selection, and allows the cursor the prioritize its nearest target, ensuring better precision and speed. The Point Cursor, by contrast, showed an increase in variability and MT in dynamic conditions, as seen by wider interquartile ranges and higher error rates. Additionally, the smaller increase in MT for the Bubble Cursor under dynamic conditions reflects its ability to reduce cognitive and motor load.

Our study's integration of gamified elements such as streak counters and dynamic difficulty adjustments, was found to increase user engagement by transforming common routine interactions into a more enjoyable experience. The introduction of different backgrounds for distinct levels not only enriched interface aesthetics but also introduced a new environment at each stage, which reduced learning effects and kept participants interested.

Despite these strengths, the study identified certain limitations that warrant further investigation and refinement. The small sample size of ten participants limits the generalizability of the findings. While this sample provided valuable insights into baseline usability and performance, a larger and more diverse participant pool would allow for a more comprehensive evaluation of the cursor's effectiveness across various user demographics and contexts. By expanding the number of participants with different levels of familiarity with digital tools, cultural, and professional backgrounds, the system may provide an even deeper understanding of its universal applicability.

Another limitation observed was that the cursor sometimes failed to detect and select very small targets or those moving at high velocities. This further puts emphasis on the need for refinements in the adjustments of the cursor's activation area and its motion-tracking and activation algorithms. Increasing the precision of the activation algorithms or adding more visual cues may improve target acquisition in high-precision tasks, thus expanding the applicability of the cursor to more demanding use cases. Futhermore, the trials were conducted in a controlled environment, which may not fully replicate real-world conditions. Dynamic environments in practical applications could present additional challenges not captured in this study.

These findings emphasize how important it is to have adaptability in cursor design for complex layouts and dynamic environments. By reducing both the physical and cognitive effort required for target acquisition, the Adaptive Bubble Cursor has demonstrated its potential to enhance user performance and satisfaction. Limitations identified in the study provide a starting point for further research on improving target precision and including more participants in order to further validate the effectiveness of the cursor and refine its features. This will not only improve its versatility but also allow it to continue to perform well in a constantly evolving digital environment.

Apart from its utility in gaming and productivity tools, the Adaptive Bubble Cursor offers wisdom on human-computer interaction design across various domains. Its basis of dynamic adaptability could help improve interfaces for AR/VR systems, where precision tracking and responsiveness are vital to its user's experience. As games and game-like designs become a core component of these Extended Reality (XR) tools, its important to prioritize ethical considerations while balancing engagement, to ensure user well-being and to mitigate the overuse of technology driven by reward mechanisms.

6 CONCLUSION AND FUTURE WORK

This study has underlined how much potential the Adaptive Bubble Cursor holds for changing the face of target selection in graphical user interfaces. Equipped with dynamic adaptation to target proximity and engaging gamified features, the Adaptive Bubble Cursor outperformed traditional Point Cursors on both accuracy and speed, especially when operating in dense and dynamic environments. These results emphasize how adaptive interaction techniques can contribute to user performance and satisfaction in a wide range of contexts.

Nevertheless, some opportunities for refinement and further exploration remain. Further work should focus on the following aspects:

- **Expanding the Participant Pool:** Studies with larger and more diverse groups of users are necessary to increase generalizability and examine such factors as age, experience, or task complexity on performance.
- **Real-world Applications:** Assessing cursor performance in real-world applications like gaming, professional design, or accessibility software to gauge the effectiveness of the technology across a wide range of tasks.
- **Refining Design for Edge Cases:** Addressing difficulties with very small or overlapping targets with improvements in the precision of the activation area and providing better visual feedback to ensure robustness in all conditions. Additionally, the study tested moving targets at moderate speeds. Future investigations should include higher target velocities, complex trajectories, and overlapping motions to assess the cursor's robustness under more demanding conditions.
- **Adaptive Extensions:** Advanced adaptive features include predictive algorithms on user intent or optimizations depending on specific tasks. This would enhance the versatility and efficiency of the cursor even more.

Addressing these areas, the Adaptive Bubble Cursor will be able to become a universally effective tool in modern GUIs for manifold applications and various users' needs. Its adaptability, combined with continuous refinements, bears the potential to set new standards in interaction design.

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