A TWO MICE FRAMEWORK FOR NAVIGATION AND SHAPE MANIPULATION IN 3D GRAPHICS

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Congyao Zheng

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A Two Mice Framework for Navigation and Shape Manipulation in 3D Graphics

Approved by:

Dr. Rossignac, Jarek, Advisor
School of College of Computing
Georgia Institute of Technology

Dr. Liu, Karen
School of College of Computing
Georgia Institute of Technology

Abstract

The increasing influences of interaction technologies like Augmented Reality(AR) and Virtual Reality(VR) has brought about about the high demand of 3D shape design and bi-manual user input devices with more degree-of-freedom (DOF). However, because alternative solutions are either slow and tedious (one hand mouse interface) or require more expensive gear and delicate set-up (such as Polyhemus, Leap Motion, Oculus VR gear, etc.), this research focused on using 2 inexpensive, off-the-shelf mice with a scroll wheel each, to develop a 6 DOF control system that could benefit animators of 3D digital movies, architects and engineers who rely on CAD tools and CAD vendors. With such 2 mice framework, we propose 2 different strategies, symmetrical and asymmetrical, to improve both popularity and usability of two hands operating in 3D virtual environment.

Introduction

The broad focus of our research is to explore the suitability of two-hand interfaces for navigation in 3D virtual space and manipulating 3D shapes. In our daily life, we execute various compound tasks relying on two hands collaborations without planning them in our minds beforehand. Taking advantages of this human bi-manual ability, we aim to develop a framework that maps 6 DOF to a simple two-handed operation set. Past experiments have proved that performing tasks with both hands can obtain higher efficiency over one-handed methods on both independent (1, 4, 5) and dependent movements (8, 9). Independent movements include tasks that require two hands carrying out different missions, while the dependent movements which happen more frequently in our daily life, according to Mason et.al, require two hands to co-operate on completing tasks. Since positive conclusions on are successfully founded, in 20th century, the development of 3D interfaces has switched from single hand devices providing 6

DOF (17) to two-handed input systems, including both hardware combination of input ports and recently gesture based tracking devices (14, 16).

However, the fact that many solutions on this problem have already been produced does not deprive our advantages in this field of 6 DOF bi-manual control system. Either the complex designed input devices, including mouse-like devices with a rolling ball, such as 3D Connexion, and pen-like interacting panels, such as Haptic Arm 3D Input Device, or gesture based tracking systems were focusing on new tool inventions rather than using user's existing gadgets. The drawbacks with such invention are high prices and the learning curve of new technology to users (Bèrard et al. 2009). Therefore, most of those 3D interfaces are unfriendly to novices who still attach to traditional input means, mouse and keyboard, so that they require time to adapt to the tools.

Taking account of the novice users who rely on using mouse, we present a framework that allows two mice connected through USB and so that provides 6 DOF, including two sets of sliders moving in x and y coordinate and two scroll wheels. The two mice can be from any brands, any price ranges, as long as they have scroll wheels which are necessary for our 6 DOF operation. The operation set should be mapped reasonably for novices who have never interacted with two-handed control or 6 DOF input devices, according to the past empirical results on bi-manual manipulation, and show two-handed control benefits -- its ease of use and further development potential. Overall, a fully analysis of user experiences, constraints, and input accuracy on our two mice control approach will be provided based on the performance measuring scheme (17, 18) and two hands cooperation tasks from Buxton and Myers' theory (14).

Methods

Human ambidextrous operation are categorized by independent (1, 4, 5) and dependent movements, while dependent movements are proved to have better performances in designed tasks (8, 9). In order to develop a solution to two mice operation in 3D virtual space, we researched on both symmetrical and asymmetrical strategies as sub-categories in dependent movements. Our experiment was developed using Processing, an open-source graphical library and integrated development environment. To record multiple input devices in all operating systems, especially, MacOS, we applied third-party libraries, GameControlPlus (19) and ManyMouse (20). After having device input queue correctly recorded, we applied a low-pass filter on input data stream to acquire more smooth rotation animation.

The filtering algorithm:

```
-Filtering buffer G;
-Current frame h;
void Filtering(raw_angle):
        Size of buffer n;
        G[h] = raw_angle;
        Low pass filter: delta t, alpha
        smoothed_rotation_angle=lowPass(rotation_angle, dt, alpha)[h];
        Update angle for last frame;
        Update h;
```

2.1 Symmetrical Solution

Our symmetrical strategy asks users to perform symmetrically with their hands, e.g. both moving away or toward from each other (figure 1). We measure the displacement vectors, M_1

and M_2, for each mouse and their wheel rotation values, α_1 and α_2. In turn, we keep track of four quantities:

1. $\frac{M_1+M_2}{2}$ Average of the displacement vectors implies the averaged direction
2. $\frac{M_1-M_2}{2}$ Half-difference between the displacement vectors implies the averaged distance
3. $\frac{\alpha_1+\alpha_2}{2}$ Average of the wheel rotation values of the two mice
4. $\frac{\alpha_1-\alpha_2}{2}$ Half-difference of the wheel rotation values of the two mice

We then distinguish horizontal and vertical motions from the measurements:

a) Moving in the same horizontal direction, measures by the average, $\frac{H_1+H_2}{2}$, of the horizontal displacement vectors H_1 and H_2 of the two mice

b) Moving in different horizontal directions, measures by the half-difference, $\frac{H_1-H_2}{2}$, of the horizontal displacement vectors H_1 and H_2 of the two mice

c) Moving in the same vertical direction, measures by the average, $\frac{V_1+V_2}{2}$, of the vertical displacement vectors V_1 and V_2 of the two mice

d) Moving in different vertical directions, measures from the half-difference, $\frac{V_1-V_2}{2}$,of the vertical displacement vectors V_1 and V_2 of the two mice

e) Scroll wheels in same direction, measures by the average, $\frac{\alpha_1+\alpha_2}{2}$, of the wheel rotation values of the two mice

f) Scroll wheels in different directions, measures by the half-difference, $\frac{\alpha_1-\alpha_2}{2}$, of the wheel rotation values of the two mice

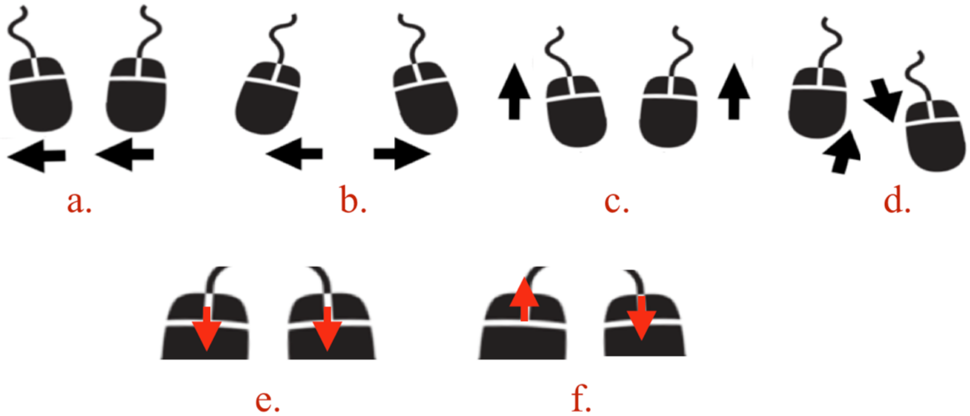

Figure 1

In the above strategies, a, b, and a controls global x, y, z axis correspondingly; d controls rotating angle relative to y axis in global frame; e and f work in local frame – two scroll-wheels control rotations relative to x and z in local frame correspondingly, so scrolling them in same and different directions result in different rotations overall.

To implement this strategy, we first record the farthest distance the user can reach with two mice. And then, based on that distance, we proportionally map users' physical mice positions, (x_{m1}, y_{m1}) and (x_{m2}, y_{m2}) to on-screen point A, (x_a, y_a), and point B, (x_b, y_b) each frame. A and B in current frame and last frame produce four vectors, AB, lastAA, lastBB, lastAlastB, which are sufficient to calculate user mice movement.

To analyze the usability of this symmetrical strategy for two hands navigation in 3D, we designed an abstract task. The task is navigating a cube frame into a certain position at a certain angle, which is also defined by a cube frame only 10% larger than the operating cube. The goal is satisfied only when eight vertices are all in positions (Figure 2). This task will convey how efficient our solution in 6 DOF operations in 3D virtual space in terms of completing time. We compare the completing time of using one mouse only and using two mice with symmetrical operations to see if there any improvements are made.

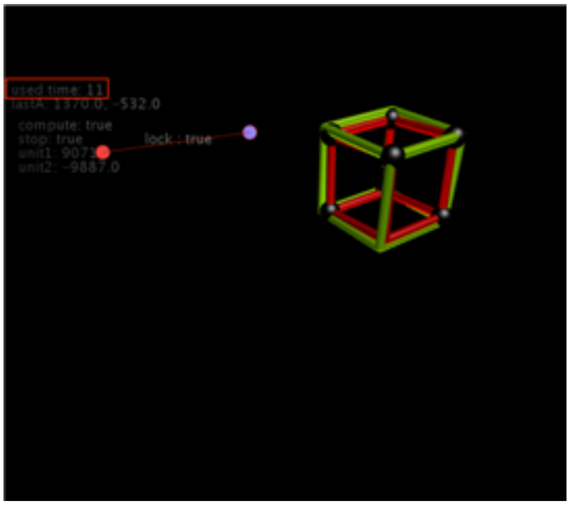

Figure 2

2.2 Asymmetrical Solution

Our asymmetrical strategy requires users to use one hand to control the global view and the other hand to take actions. It is like peeling off the peel of an apple – using one hand holding the apple, and using the other hand to perform the peeling operation with a knife.

offers an effective solution to 3D knotting topology problem. Our asymmetrical solution offers below operations on each hand (a, b, and c apply on both hands):

a) moving horizontally

b) moving vertically

c) wheel scrolling up/down

The hand controlling global view, we will call it control hand; the hand taking action, we will call it operate hand. In our framework, the left and right concept do not matter – users can switch mice or sides to their preference freely. The control hand moves horizontally and vertically to rotate the global view, which can be considered as a large cubicle that user is operating in, while scrolling the wheel up or down controls an operating plane, which exemplifies a desk where users do manipulations or modifications. The operate hand therefore controls anything that can be operated on that operating plane correspondingly. The specific implementation for operate hand can vary from different applications.

To test the asymmetric strategy, we designed a task of making knots in 3D virtual space. The perform hand is like holding a virtual thread end, moving freely to draw the thread anywhere the user wants. The control hand can rotate or move a plane where the perform hand is drawing on. A cube frame is shown to help the user to understand the 3D space. In below illustration, the bright yellow indicates where the plane intersects with the cube frame, so that it casts a better representation of where the user is at (Figure 3). The strokes are always drawn right on the yellow plane, so that even the perform hand is not moving, a 3D stroke will be drawn if the control hand is moving the plane (Figure 4).

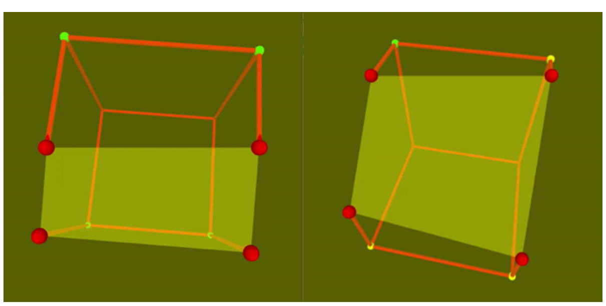

Figure 3

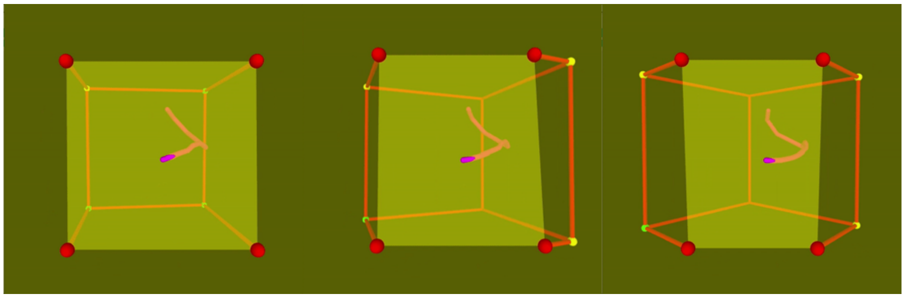

Figure 4

Result

While other solutions have learning curves for novice users, we want to prove our strategies are simpler for mouse users to adapt to. We conducted user study on 5 users who have never involved in 3D graphics design and compared the time cost using our two strategies and using one mouse in corresponding tasks. We used one Logitech mouse (about $15) and one Miniso mouse (about $3) in our user tests. The average time of completing navigation task using our symmetric strategy is not better than using one mouse with keyboard help (Figure 5).

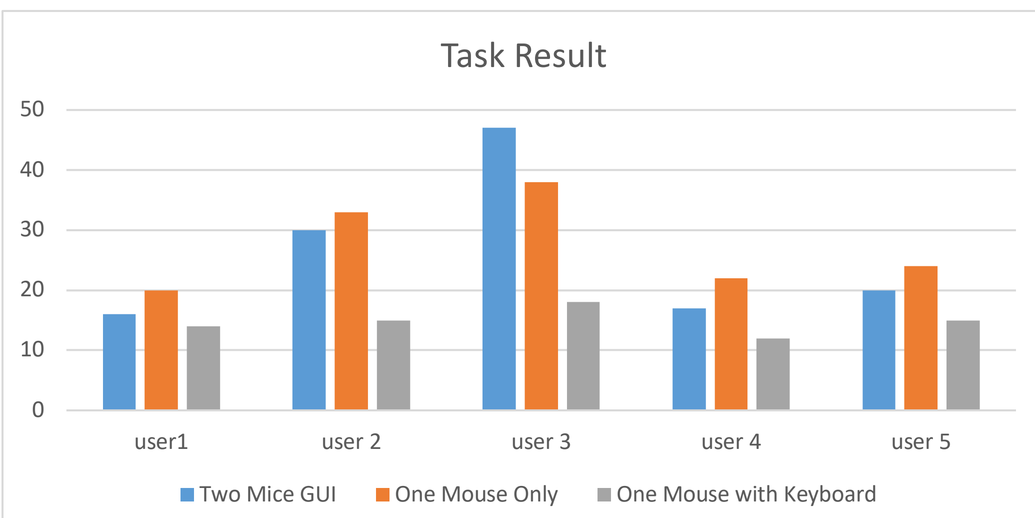

Figure 5

For our knot-making task, we showed to users a knot which they can touch, feel, unknot, or loosen in real world and then make the knot in virtual space (Figure 6). All five users found it is impossible to make the given knot with one mouse, while they easily lose track on where they are during view-changing.

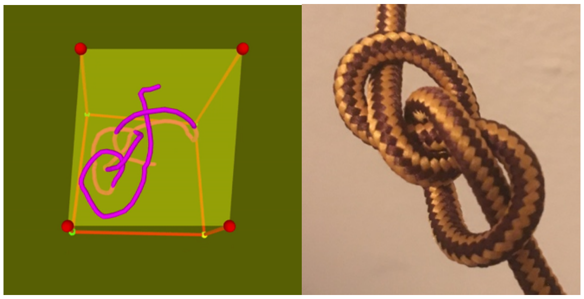

Figure 6

Discussion

The factor of accuracy impacted our symmetric-navigation task significantly. Usually, the task is divided into two parts by users: first move the red cube into the green cube's position, and then rotate to the expected status. To comprehensively demonstrate and combine the rotating operation and the movement operation together in mind is the hard part. Therefore, by dividing the task into two processes, users eased the operating but failed to utilize the feature of the strategy, which is operating with 6DOF simultaneously.

Due to the same reason, according to previous researches on bimanual tasks, our the asymmetric control-perform solution is more related to human hands co-operations, so that it works much better and show great disparity with 3 DOF.

Future Works

Currently our framework only work with wired or wireless USB mice. In the future, we want to also include Bluetooth mice in our system. In addition, because the asymmetric strategy works surprisingly well for knotting in virtual space, we want to further develop weaving applications and solve weaving topology in 3D using our two mice GUI.

References

1) Buxton, W., & Myers, B. (1986). A study in two-handed input. *ACM SIGCHI Bulletin*, *17*(4), 321–326. http://doi.org/10.1145/22339.22390

2) Bérard, François, et al. “Did ‘Minority Report’ Get It Wrong? Superiority of the Mouse over 3D Input Devices in a 3D Placement Task.” Human-Computer Interaction – INTERACT 2009 Lecture Notes in Computer Science, 2009, pp. 400–414., doi:10.1007/978-3-642-03658-3_45.

3) Gribnau, M. W., & Hennessey, J. M. (1998). Comparing single- and two-handed 3D input for a 3D object assembly task (pp. 233–234). Presented at the CHI 98 conference summary, New York, New York, USA: ACM Press. http://doi.org/10.1145/286498.286720

4) Kabbash, P., Buxton, W., & Sellen, A. (1994). Two-handed input in a compound task. Presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, Massachusetts, USA: ACM. http://doi.org/10.1145/191666.191808

5) Leganchuk, A., Zhai, S., & Buxton, W. (1998). Manual and cognitive benefits of two- handed input: an experimental study. *ACM Transactions on Computer-Human Interaction*, *5*(4), 326–359. http://doi.org/10.1145/300520.300522

6) Llamas, I., Kim, B., Gargus, J., Rossignac, J., & Shaw, C. D. (2003). Twister: a space- warp operator for the two-handed editing of 3D shapes. Presented at the ACM SIGGRAPH 2003 Papers, San Diego, California: ACM. http://doi.org/10.1145/1201775.882323

7) Llamas, I., Powell, A., Rossignac, J., & Shaw, C. D. (2005). Bender: a virtual ribbon for deforming 3D shapes in biomedical and styling applications. Presented at the Proceedings of the 2005 ACM symposium on Solid and physical modeling, Cambridge, Massachusetts: ACM. http://doi.org/10.1145/1060244.1060255

8) Marteniuk, R. G., MacKenzie, C. L., & Baba, D. M. (2007). Bimanual movement control: Information processing and interaction effects. *The Quarterly Journal of Experimental Psychology Section A*, *36*(2), 335–365. http://doi.org/10.1080/14640748408402163

9) Mason, A. H. (2007). Performance of Unimanual and Bimanual Multiphased Prehensile Movements. *Journal of Motor Behavior*, *39*(4), 291–305. http://doi.org/10.3200/JMBR.39.4.291-305

10) Mason, A. H., & Bruyn, J. L. (2009). Manual asymmetries in bimanual prehension tasks:

Manipulation of object size and object distance. *Human Movement Science*, *28*(1), 48–73. http://doi.org/10.1016/j.humov.2008.09.002

11) Mendes, D., Relvas, F., Ferreira, A., & Jorge, J. (2016). The benefits of DOF separation in mid-air 3D object manipulation. Presented at the Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology, Munich, Germany: ACM. http://doi.org/10.1145/2993369.2993396

12) Nagai, K., Tanoue, S., Akahane, K., & Sato, M. (2015). Wearable 6-DoF wrist haptic device "SPIDAR-W." Presented at the SIGGRAPH Asia 2015 Haptic Media And Contents Design, Kobe, Japan: ACM. http://doi.org/10.1145/2818384.2818403

13) Shaw, C. D., & Green, M. (1997). THRED: a two-handed design system. *Multimedia Systems*, *5*(2), 126–139. http://doi.org/10.1007/s005300050048

14) Siegl, C., Süßmuth, J., Bauer, F., & Stamminger, M. (2014). Evaluating the Usability of Recent Consumer-grade 3D Input Devices. *Grapp*.

15) Veit, M., Capobianco, A., & Bechmann, D. (2009). Influence of degrees of freedom's manipulation on performances during orientation tasks in virtual reality environments, 51–58. http://doi.org/10.1145/1643928.1643942

16) Wang, R., Paris, S., & Popović, J. (2011). 6D hands (pp. 549–558). Presented at the the 24th annual ACM symposium, New York, New York, USA: ACM Press. http://doi.org/10.1145/2047196.2047269

17) Zhai, S. (1998). User performance in relation to 3D input device design. *SIGGRAPH Comput. Graph.*, *32*(4), 50–54. http://doi.org/10.1145/307710.307728

18) Zhai, S., & Milgram, P. (1993). <title>Human performance evaluation of isometric and elastic rate controllers in a six-degree-of-freedom tracking task</title>. In W. S. Kim (Ed.), (Vol. 2057, pp. 130–141). Presented at the Optical Tools for Manufacturing and Advanced Automation, SPIE. http://doi.org/10.1117/12.164895

19) Lager, Peter. *Game Control Plus*. Jar. Http://lagers.org.uk/.

20) Gordon, Ryan C. *ManyMouse*. Https://icculus.org/.