The Number Wheel:

A Tablet Based Valuator for Interactive Three-Dimensional Positioning

Robert W. Thornton[1]

Carnegie-Mellon University
Pittsburgh, Pennsylvania

A logical valuator device which provides interactive graphical input of numeric values is presented. This device, called the *Number Wheel*, was developed for interactive control of highly dynamic three-dimensional displays but is not limited to this use: it is a general purpose valuator device. The implementation of the Number Wheel described here is based upon a digitizer tablet as the physical input device.

The character of the Number Wheel is best explained by developing an analogy with a hypothetical physical device. The Number Wheel can be thought of as a wheel which has a portion of its circumference, or tread, protruding through a slot on the surface of the tablet, somewhat like a giant thumb wheel. Each value in the desired range of the valuator is represented by a point on the circumference of the wheel with the value of the device at any given time being the point at the top of the wheel. The valuator is changed by putting the pen on the wheel where it protrudes through the tablet and moving it back or forth in the direction of rotation. Whenever the pen leaves the rim of the wheel while still moving, the Number Wheel maintains the same speed of rotation until the pen returns to the wheel in order to change or stop its movement.

Key Words and Phrases: **graphic display, graphic input, interactive graphics, interactive input, logical input device, numeric value input, real-time graphics, tablet input, valuator input device, 3-D dynamic graphics**

CR Categories: **3.9, 4.41, 6.35, 8.2**

1. Introduction

The Number Wheel is a graphic input device whose development was motivated by the need for accurate and convenient interactive control over dynamic displays of three-dimensional shapes such as rotation or other animated motion. The Number Wheel is a logical *valuator* device (allowing input of a numerical value) whose implementation is based upon a *locator* device (which allows input of locations in a space of one or more dimensions)[2]. A group of Number Wheels is used to control the three-dimensional display by associating a particular Number Wheel's value with each of the view parameters under control such as angles of rotation, location of viewpoint, angle of view, etc.: as the user changes a Number Wheel's value the three-dimensional display is updated in conjunction with the new value of the associated view parameter.

As stated before, the Number Wheel is based on a locator device. This locator may be either the relative positioning type, such as a "*mouse*" (see [5]), or the absolute type, such as a digitizer tablet. Most multi-dimensional locators such as two-dimensional tablets, the mostly one-of-a-kind three-dimensional digitizers (see [4] for mechanical, [1] for sonic, or [3] for LED based examples), or many-dimensioned remote manipulators might be used effectively for controlling sets of Number Wheels. The only additional requirements for the locator are that updated locations must be available many times per second (60 per second is commonly used, 20 per second is adequate) and there must be a switch for the user to turn this stream of locations on or off (such as a function button on a "mouse" or the pen-point switch found on many

---

[1]Mailing address: Robert W. Thornton, Carnegie-Mellon University, SUPA - Schenley Park, Pittsburgh, PA 15213, USA.

[2]For a discussion of logical graphic input devices and a description of various classes of such devices, see, for example, [8, 9].

tablets). The description of the Number Wheel as presented here will assume the use of a tablet-pen locator. This input device has the ability to provide many forms of input through a single physical device and is available at a relatively low cost.

2. Functionality

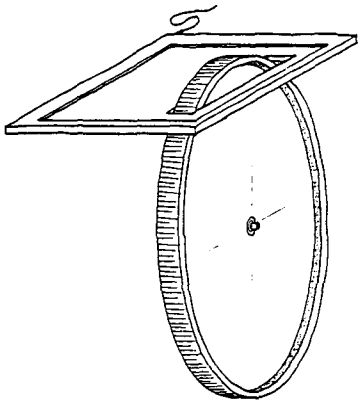

Figure 1: Hypothetical physical analogy of the Number Wheel

The character of the Number Wheel is best explained with the use of a physical analogy: by describing a hypothetical device which operates in a fashion similar to the logical Number Wheel device. It is from this physical analogy that the name "Number Wheel" is derived.

The Number Wheel can be thought of as a wheel which has a portion of its circumference protruding through a slot on the surface of the tablet, somewhat like a giant thumb wheel, as illustrated in Fig. 1. Each value in the desired range of the valuator is represented by a point on the circumference of the wheel with the value of the device at any given time being the point at the top of the wheel. The valuator is changed by putting the pen on the wheel where it protrudes through the tablet and moving it back or forth in the direction of rotation. Whenever the pen leaves the rim of the wheel while still moving, the Number Wheel maintains the same speed of rotation (i.e. rate of change in value) until the pen returns to the wheel in order to change or stop its movement.

The number of discrete values possible for the portion of the Number Wheel's rim which is accessible through the surface of the tablet at a given instant is limited by the resolution of the tablet. However, the resolution of the Number Wheel over its entire range is not limited by the tablet and is adjustable by varying the size (diameter) selected for the hypothetical wheel. Since the wheel has no mass (and hence no momentum) and is mounted on frictionless bearings, it is very easy to push the wheel and start it rotating very quickly. It can also be stopped "on a dime" when a desired value is reached. Thus it is possible to make gross changes in a Number Wheel's value very quickly yet also perform precise selections of value at the level of the valuator's pre-determined resolution.

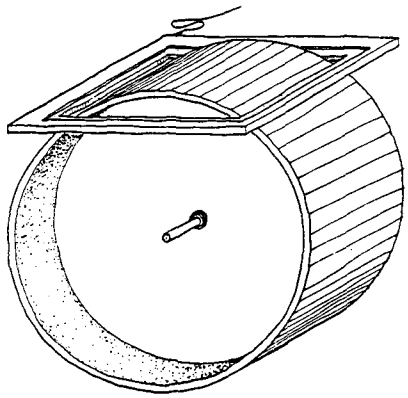

Figure 2: Analogical Number Wheel with different size and orientation.

Where the Number Wheel illustrated in Fig. 1 is manipulated by moving the pen forward and backward over a narrow window on the tablet, the size, shape, and location of the window through which a Number Wheel protrudes may vary for different uses. Figure 2 illustrates a Number Wheel which covers the entire surface of the tablet in addition to having a different direction of rotation: it is changed by moving the pen left and right. Other alternatives might include several separate Number Wheel's each accessible through separate windows on the tablet at the same time, or even more than one Number Wheel available simultaneously through the same tablet window, each with a different direction of rotation.

3. Examples

An example of how Number Wheels might be used will be developed by continuing with the physical analogy just presented. Going back to the original need expressed for developing the Number Wheel, one can be configured for interactively controlling the rotation of a three-dimensional object being displayed. Using the Number Wheel illustrated in Fig. 2 and assigning the values from zero to 359 around the circumference of it, the current value (the number at the top) of this Number Wheel can be used to indicate

the angle of rotation, in degrees, of the three-dimensional object on display about the y-axis.

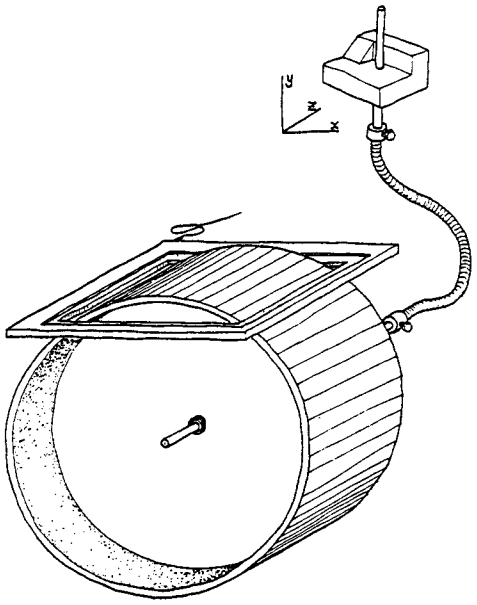

Figure 3: Number Wheel used to control rotation of object about y-axis.

The hypothetical physical mechanism which we are modeling for this application is illustrated in Fig. 3. There is a three-dimensional object in front of us which is connected with the Number Wheel by a flexible cable through its y-axis. As the wheel is rotated with a left or right movement of the pen, the object rotates in a direction and speed corresponding to the movements of the pen.

In a similar manner, a Number Wheel with its axis turned 90 degrees so that it rotates with a forward/backward motion might be used to control the rotation of the three-dimensional object about the x-axis. Another hypothetical mechanism which illustrates this action is shown in Fig. 4. This could be carried further by placing both of these Number Wheels in the same tablet window at the same time so that any combination of forward/backward and left/right movements can provide a desired combination of rotations about the x and y axes (illustrated in Fig. 5).

Similarly, other Number Wheels may be defined which control other parameters of the display transformation, such as translations in various directions, angle of vision, positioning of section planes, or for the arbitrary axis rotations as presented in [2].

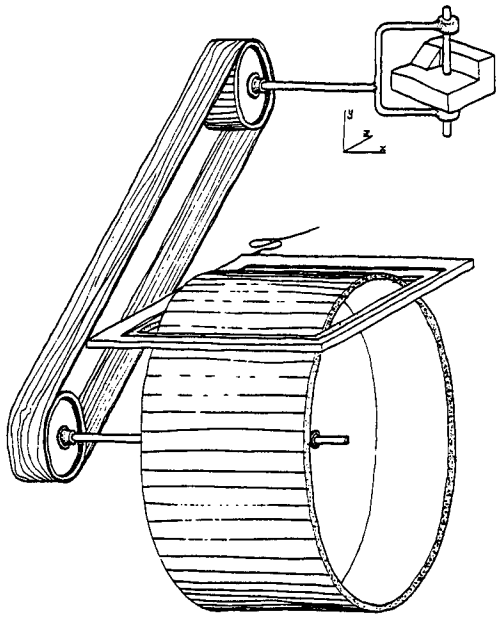

Figure 4: Hypothetical mechanism controlling x-axis rotation.

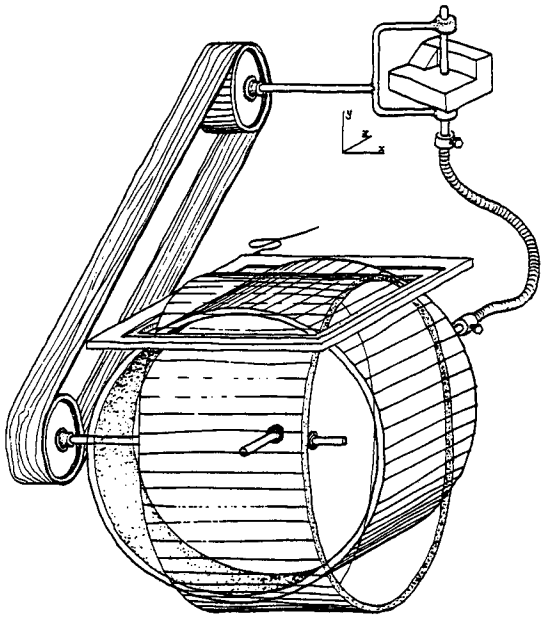

Figure 5: Hypothetical mechanism controlling combined x and y axes rotations.

4. Implementation

This section describes one particular way of implementing Number Wheels which has been found to

be capable and flexible. There are, however, many other approaches which could be taken to provide different features. A following section suggests some of these variations and extensions.

Implementing a particular Number Wheel is fairly straight forward. A procedure to update an *active* Number Wheel must be performed at each time interval (e.g. $^1/_{60}$ second). If the pen is down on the rim of the wheel (i.e. surface of the tablet) then the *incremental change* for the Number Wheel must be recalculated by taking the relative change in position of the pen since the last time period (if the pen was also down last time) and scaling it by a value which provides the desired amount of resolution over the Number Wheel's range. The current incremental change (possibly zero) is then added to the *current* value of the Number Wheel. At this time the value must also be tested to see if it has reached one of the limits of the valuator's defined range. If it has, there are at least two possible courses of action:

- Reset the Number Wheel's value to its opposite limit and allow it to continue changing in the same direction (*wrap* around). This is similar in result to a continuous-turn rotary type potentiometer. This type of action might be used for a valuator which controls the angle of rotation about a particular axis of an object on display. The maximum and minimum might be 359 degrees and zero degrees so when the Number Wheel is pushed up to and past 359 degrees, the object will continue rotating in the same manner as the valuator wraps around to zero.

- Simply stop changing the value of the Number Wheel; leaving it at the limit until such time that it is turned back in the opposite direction. This type of action might be used for a valuator which is controlling the angle of vision for a three-dimensional display. For example, the maximum and minimum values might be 179 degrees and one degree. When the user pushes the Number Wheel to zoom in on the object, it stops upon reaching one degree and the only available action is to zoom back out.

The current value of the Number Wheel may be used as required in calculating a display update or otherwise.

For most applications, more than one Number Wheel will be used. Additional logic must then be provided to determine which Number Wheel (or *gang* of Number Wheels, if two or more are to be controlled simultaneously in the same area of the tablet) the pen is currently controlling, and/or switches to control which set of Number Wheels is available through the surface of the tablet at any given time.

To make it easy to implement Number Wheels for different programs and make it a simple process to add Number Wheels or dynamically change existing Number Wheels (perhaps with another Number Wheel controlling one of its parameters!) in a running program, this implementation has a generalized design. A table is utilized to hold the parameters which define the characteristics of the individual valuators, in addition to the few variables required in the operation of each, such as the current value of the Number Wheel, whether it is currently active (at the surface of the tablet) or not, the incremental change, etc. All that is required to add a new Number Wheel or change the character of an existing one is to add or change an entry in this table.

A set of six parameters has been selected which allow simple specification of a large class of different Number Wheels. They are:

- The minimum value allowed for the range of the Number Wheel.

- The maximum value in the range.

- The number of units of resolution in the valuator's range or distinct steps between the minimum and maximum values. It should be noted that the resolution of the physical input device does not limit this parameter or the two previous ones: they are only limited by the numerical representation used in the calculations.

- The number of units of resolution on the input device which are to correspond to one of the above defined units of resolution of the logical valuator. This parameter, in conjunction with the previous one establishes the ratio between the physical distance the pen is moved and the amount that the valuator changes.

- The type of *limit* condition desired. The choices for this are either "wrap around" or "stop", explained earlier in this section.

- An indication of which *controlling variable* is to be used. This variable controls the incremental change used in updating the Number Wheel and will normally be the change in the pen's location, from one time period to the next, in either the x or y direction.

It might also be desirable to identify a particular window or sub-area of the tablet through which each particular Number Wheel appears. However, experience has shown that it is usually more convenient for each Number Wheel to cover the entire surface of the tablet with the added provision of a set of logical buttons with which the user may select one or two of a set of Number Wheels to be available on the tablet at any given time. This frees a user of the need to put the pen down on a particular area of the tablet while using a Number Wheel; allowing one to concentrate on viewing the display as opposed to worrying about the location of the pen on the tablet. This might seem a small point but it adds to the ease of use or habitability of the system and thus improves the ability to quickly gain a complete perception of the three-dimensional forms being displayed.

Additional details and more complete descriptions of use of the Number Wheel may be found in [7].

5. Extensions

In addition to its application to dynamic three-dimensional positioning, the Number Wheel will function well for many other uses as a general interactive valuator device. An even larger class of valuators is possible using the same basic logic described here for the Number Wheel by expanding the dimensions of variation described earlier. Examples of these variations are:

- Use of controlling variables other than the change in x or y position of a pen on tablet to calculate the incremental change for the valuator. These might include the absolute pen coordinates (as opposed to relative to the previous position), the change in x or y position modified by some non-linear function to provide a wider range of velocities of change, or values obtained from other physical devices such as remote manipulators, rotary potentiometers, or joysticks: providing an extra level of flexibility over the physical devices.

- An additional definitional parameter could be used to apply braking to a freely rotating Number Wheel. This might be thought of as specifying the amount of friction in the bearings of the wheel, going back to the previously made physical analogy of the Number Wheel. This would control the amount of time required for a Number Wheel to slow to a stop when left rotating.

- In addition to the above friction parameter, it might be desirable to have a *spring return* which pulls the valuator back to a "home" position when released.

- Additional alternative responses to reaching a Number Wheel's range limit might be provided, such as switching the direction of change, or "bouncing back" in the opposite direction when a limit is reached.

- Finally, for some applications it might even be helpful to be able to define a non-continuous range over which the valuator may operate.

6. Summary

For the interactive control of three-dimensional positioning, for which the Number Wheel was originally designed, it has proven to be a very convenient and flexible device, overcoming many of the limitations found in previously used logical valuators (such as logical slide potentiometers, rate controls, or the well known "Light Handle" [6]) and physical valuators (such as potentiometers or joysticks). Characteristics of the Number Wheel contributing to its success include:

- The resolution is limited only by the numerical representation used.

- Gross changes in value can be made quickly and easily.

- There is a capacity for easy "fine tuning" of specific values at the level of the Number Wheel's resolution.

- Smooth and continuous change of value many times per second are provided for controlling updates of a dynamic display.

- There is a choice of how the limit condition is handled, something not found

in most physical devices.

- A particular rate of change may be set initially which is automatically continued indefinitely without further action from the user.

- There is a close correspondence between the numerical value being changed and the physical movements required by a user to control such change. This is provided in three manners: when the pen is on the tablet the value changes when the pen moves and not when it is still (as is done in tablet based valuators which control the **rate** of change), the value can change in a direction which corresponds to the direction of pen movement, and the value changes at a speed relative to the speed of the initiating pen movement.

- Interactive control of a dynamic numeric value does not require the constant attention of the user to the fact that he is controlling a numeric value as such.

- The use of Number Wheel controls is easily learned and feels "natural" to the user: desired results are obtained with speed and ease.

Many uses of computer graphics to display projections of three-dimensional shapes are to impart some additional perception of the actual three-dimensional form to a human user. It is common to use several *cues* in trying to enhance this three-dimensional perception, such as perspective projection, decreasing intensity of lines with their distance from the observer position, removing hidden lines, and shaded surface displays. Even with all of these static three-dimensional cues, the single most effective aid to spatial perception is a user's ability to interactively animate movement of the object as he might desire. The extent to which the user can accurately and naturally control such motion can have a large effect upon the user's complete perception of the three-dimensional space. The use of the Number Wheel can help shorten this step to complete perception.

References

1. Brenner, A. E. and de Bruyne, P. A sonic pen: a digital stylus system. *IEEE EC-19*, 6 (June 1970), 546.

2. Britton, E. G., Lipscomb, J. S., and Pique, M. E. Making nested rotations convenient for the user. Proceedings SIGGRAPH 78: Fifth Annual Conference on Computer Graphics and Interactive Techniques, ACM - SIGGRAPH, August, 1978, pp. 222-227.

3. Burton, R. P. *Real-time measurement of multiple three-dimensional positions*. Ph.D. Th., University of Utah, 1973.

4. Clark, J. H. Designing surfaces in 3-D. *Comm. ACM* 19, 8 (August 1976), 454-460.

5. English, W. K., Englebart, and D. C., Berman, M. L. Display-selection techniques for text manipulation. *IEEE Transactions on Human Factors HFE-8*, 1 (1967), 5.

6. Newman, W. M. A graphical technique for numerical input. *Computer Journal 11* (May 1968), 63-64.

7. Thornton, R. W. MODEL - Interactive modelling in three dimensions through two-dimensional windows. Master Th., Cornell University, January 1977.

8. Trambacz, U. Towards device independent graphics systems. Proceedings SIGGRAPH 75: Second Annual Conference on Computer Graphics and Interactive Techniques, ACM - SIGGRAPH, Spring, 1975, pp. 49-52.

9. Wallace, V. L. The semantics of graphic input devices. Proceedings ACM Symposium on Graphic Languages, ACM - SIGGRAPH/SIGPLAN, Spring, 1976, pp. 61-65.