Establishment of Reference Coordinates for Free-hand Sketching

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Abstract. It is necessary to construct and manipulate the referenced coordinate system and the working plane in the free-hand sketching system in a natural way that meets the habits of stylists. This paper has presented some methods in the functions of the referenced coordinate system and the working plane, which apply the gesture commands sketched, and the combination of the hot-key and the digital pen to deal with the functions that differ from the traditional methods in the current CAD systems.

Introduction

The free-hand sketching has been more and more popular recent years. Many researchers have focused on it and presented many systems [1-6]. The gesture commands are the very important part in these systems to give a different way as nature as possible while sketching. Many of them are sketched in a single stroke and then identified as the designed commands, such as select, delete, undo and redo, etc [7,8].

In the traditional automotive conceptual design, stylist uses a pen to sketch on paper. In general, it will start from the axis lines, wheels, and then the other features [9]. A referenced coordinate system will be among the designer’s mind, even though different stylists sketch varies, as shown in Fig.1. Therefore, it is necessary to present such a coordinate system for sketching reference.

![Figure 1. Auxiliary lines in the traditional automotive sketches [10].](image)

The referenced system includes the datum planes based on the automotive body coordinate system, auxiliary grids, wheels and the working plane.

Definitions

Definition of Working Plane

The working plane is a virtual flat plane in a narrow sense or a curved plane or surface of object in a broad sense, on which the stroke or curves are drawn. It is a very useful tool to create a spatial curve...
from the planer screen stroke; it has its own coordinate system and is generally set to a translucent rectangular plane; its actual size is unlimited extension of the plane; and its apparent size can be changed manually by the user, as shown in Fig.2a; it has three orthogonal places and can be manipulated in any places and directions, as shown in Fig.2b.

![Figure 2. Working planes in AutoSketch [6].](image)

**Coordinate Systems and Transformations**

There are three coordinate systems: the logical device coordinate system (LDC) is a two-dimensional reference system, in which its origin is at the lower left corner \( O(0,0) \) and its maximum point is at the upper right corner \( F(1,1) \), as shown in Fig.2c. The values of point getting from the digital pen are two dimensional real ones within the range of \([0.0, 1.0]\); the world coordinate system (WC) is a global or absolute spatial one; the working plane coordinate (WPC) is a local one, in which the xy plane is the default drawing plane. The coordinates of a point can be changed from one coordinate system to another one. The point \( p_{wc}(x, y, z) \) in WC should be projected at first on the working plane, and then converted into the point \( p_{wpc}(x, y, z) \) in WPC.

**Determination of Perspective View and Establishment of Working Plane**

The perspective view of the world coordinate system can be manipulated by rotating or scaling the viewport. Here presents a novel way to determine the world coordinate system, which is similar to the automotive sketch referenced.

At first, two straight stroke are sketched, as shown in Fig.3, which are fit into two segments \( p_1p_2 \) and \( p_3p_4 \) by the least square linear fitting; the cross-point \( p_c(x_c, y_c) \) of two segments can be calculated as follow:

\[
\begin{align*}
    x_c &= (b_1-b_2)/(k_2-k_1) \\
    y_c &= (k_2b_1-k_1b_2)/(k_2-k_1)
\end{align*}
\]

(1)

Where \( b_1, b_2 \) are the intercepts, and \( k_1, k_2 \) are the slopes of two segments respectively. The third stroke is sketched and then fit into the segment \( p_5p_6 \), which is crossed with the extension line of the segment \( p_1p_2 \), and the cross-point is the vanishing point \( v_{p1} \); here assume that two vanishing points are on the same horizontal line, therefore, the vanishing point \( v_{p2} \) is the orsspoint of the segment \( p_3p_4 \) and the horizontal line; the third vanishing point \( v_{p3} \) can be determined by the vertical line of passing the crosspoint \( p_c \) and the segment \( p_2p_6 \); finally, the perspective center can be calculated out to determine a coordinate system, which is similar to the automotive sketch referenced [11, 12].
The simplest way to establish a working plane is to draw a point, which is as the origin of the working plane coordinate system, \( w_p \). The directions of axes are the same as that of the world coordinate system. Another way is to select a surface of object as a working plane.

**Manipulation of Working Plane**

The manipulations of the working plane are to take advantage of the merits of ThinkDesign working plane and improve or combine the original functions in order to make them closer to the habit of free-hand sketching on paper. These manipulations include translation, orthogonal switching, locating on a curve, and so on.

**Planar Translation**

The planar translation of the working plane is to move the origin of it to a new target point in the \( XY \) plane. The working plane should be selected at first, and then moved along the \( X \) or \( Y \) axis to the target point \( O' \), as shown in Fig.4a. This way is not suitable for the free-hand sketching. Obviously, the only change is the position of origin. The result is shown in Fig.4b, the working plane is selected by a gesture command \( \checkmark \), and then is moved actively to \( O' \).

![Figure 3. Determine the world coordinate system.](image)

![Figure 4. Planar translation in \( XY \) plane.](image)

**Spatial Translations**

The spatial translations are to change the \( x \), \( y \) or \( z \) value according to the requirement. In ThinkDesign, it is manipulated along the separate axis each time, for example, choosing the \( z \)-axis and then moving the mouse up or down to move it, as shown in Fig.5a. This method is precise but not intuitive. Here a novel method has been presented to give an intuitive translation in space. In order to differ from the planar translation, the hot keys are joined into the translations, Ctrl, Shift and Tab for moving along the \( x \), \( y \), and \( z \) axis respectively. The spatial translation are clear and intuitive with a dashed reference cube, as shown in Fig.5b.
The value of $\Delta z$ is calculated as follows. Assume that $p_z$ is a fixed unit point along the $z$-axis, the distance $d_{0z}$ is from the origin $O(x_0, y_0)$ of the working plane to the point $p_z(x_{pc}, y_{pc})$, which is the real distance in WPC, as shown in Fig. 5c.

$$d_{0z} = \sqrt{(x_{pc} - x_0)^2 + (y_{pc} - y_0)^2}$$ (2)

The linear equation passing the mouse point $p_m(x_m, y_m)$ can be obtained by $k_1$, and the one passing the point $p_4$ is gotten by $k_2$, and then the cross-point $p_c(x_c, y_c)$ can be calculated as follows:

$$\begin{cases} x_c = (a - b)/(k_2 - k_1) \\ y_c = k_1 \cdot x_c + a \end{cases}, \text{ where } \begin{cases} a = y_m - k_1 \cdot x_m \\ b = y_{p4} - k_2 \cdot x_{p4} \end{cases} \text{ and } \begin{cases} k_1 = \Delta y / \Delta x \\ k_2 = -\Delta x / \Delta y \end{cases}$$ (3)

Finally, the distance $\Delta z$ in WPC is:

$$\Delta z = d/d_{0z}, \text{ where } d = \sqrt{(x_m - x_c)^2 + (y_m - y_c)^2}.$$ (4)

The test results show that this method gives a good performance; it is not only intuitive, but also can follow the digital pen especially in $z$ direction.

**Orthogonal Switching**

It is necessary to switch the working plane among three orthogonal planes, $XY$, $YZ$ or $ZX$, in order to sketch in the different directions. The operation of switching in ThinkDesign is to double-click the circle at the end of each axis; the working plane will be rotated 90° along the axis each time, as shown in Fig. 6a. Such an operation is clearly inconsistent with the user’s habits, and it is not a good way to double-click the digital pen, therefore, the ticking method has been proposed to meet the requirement of sketching. For instance, if the $YZ$ plane is selected as the current working plane, just tick it as shown in Fig. 6b, which is a select gesture command. This method includes three parts: angle calculation, section judgment and rotating the working plane.
In the angle calculation part, the origin point and three unit vector points in WC are determined as \( p_w0, p_wx, p_\theta y \) and \( p_wz \), which are converted into the points \( p_0, p_1, p_2 \) and \( p_3 \) in LDC, as shown in Fig. 7a, and then translated to the origin of LDC as the points \( p_0(0,0), p_1, p_2 \) and \( p_3 \), as shown in Fig. 7b, in order to calculate the angles easily.

![Diagram](https://via.placeholder.com/150)

**Figure 7. Changing the coordinate system.**

The angles between the segment \( p_0p_1 \) and \( X_0, p_0p_2 \) and \( X_0, p_0p_3 \) and \( X_0 \) or \( p_0p_4 \) and \( X_0 \) are \( \alpha_0, \alpha_1, \alpha_2 \) or \( \beta \), respectively, which are calculated as follows:

\[
\begin{align*}
\alpha_0 &= \arctan(y_0/x_0) \\
\alpha_1 &= \arctan(y_1/x_1) \\
\alpha_2 &= \arctan(y_2/x_2) \\
\beta &= \arctan(y_4/x_4)
\end{align*}
\]

(5)

The three angles \( \alpha_0, \alpha_1, \alpha_2 \) are then ordered in value and the minimum angle is at the head. When the select gesture command is drawn out like the sign “✓”, in the section judgment part, the knee point \( p_4 \) is used to judge which section it locates. Note that in the case of the coordinate system flipped horizontally, the related sections and angles need to be calculated again.

It can be divided into three situations to carry on the judgment: \( \alpha_0, \alpha_1 \) or \( \alpha_2 \) is the maximum value, respectively. For example, it is easy to find that the order of angles is \( \alpha_1 > \alpha_0 > \alpha_2 \), as shown in Fig. 8a. When \( \beta < \alpha_2 \) or \( \beta > \alpha_1 \), the knee point \( p_4 \) is located between the \( Y \)-axis and \( Z \)-axis, it means that the user selects the \( YZ \) plane as the current working plane. If in the case of the coordinate system flipped horizontally, as shown in Fig. 8b, the order of angles is \( \alpha_1 > \alpha_2 > \alpha_0 \), \( p_4 \) is located between the \( X \)-axis and \( Z \)-axis, the \( XZ \) plane is selected.

![Diagram](https://via.placeholder.com/150)

**Figure 8. Section judgment of the current working plane.**

It can be divided into three situations to carry on the judgment: \( \alpha_0, \alpha_1 \) or \( \alpha_2 \) is the maximum value, respectively. For example, it is easy to find that the order of angles is \( \alpha_1 > \alpha_0 > \alpha_2 \), as shown in Fig. 10a. When \( \beta < \alpha_2 \) or \( \beta > \alpha_1 \), the knee point \( p_4 \) is located between the \( Y \)-axis and \( Z \)-axis, it means that the user selects the \( YZ \) plane as the current working plane. If in the case of the coordinate system flipped...
horizontally, as shown in Fig.10b, the order of angles is \( \alpha_1 > \alpha_2 > \alpha_0 \), \( p_{pi} \) is located between the X-axis and Z-axis, the XZ plane is selected.

In the rotating part, the current working plane is rotated 90\(^\circ\) each time, as shown in Fig.8b, for instance, the YZ plane is rotated 90\(^\circ\) along the X-axis, and then the XZ plane is rotated 90\(^\circ\) along the Y-axis. Note that the current working plane is always in XY plane, that is, the selected YZ plane becomes the XY plane finally.

**Size Setting**

The working plane is an unlimited extending plane, on which the user can sketch. It can be seen in the translucent form and with a coordinate system, which can give users the feeling of working region. However, the default size of the working plane in ThinkDesign is too small to be seen, in addition, it is difficult to see the switching of the working plane and confirm the correct operation. The size of the working plane can be changed by moving the points at the four corners of the working plane, as shown in Fig.9a.

![Image of Size Setting](image)

Figure 9. Changing the size of the current working plane.

In the free-hand sketching, the operation will become very complicated if user frequently clicks the corner points with digital pen to adjust the size of the working plane. Therefore, it should be big enough. It is connected with the size of autobody reference coordinate system, as shown in Fig.9b, the default size is set as 300mm×300mm, which is suitable after testing.

**Locating or Moving on a Curve or Surface**

In the current three-dimensional design software, several steps are needed to locate the working plane on an object, which may be a sketch, curve, surface, or plane. Sometimes the direction and the origin of the working plane are also needed. In the free-hand sketching system, the curves are often dealt with. The main role of locating or moving the working plane on a curve is to assist the creation of spatial curve, determine the direction and length of extension while extruding a curve into a surface, select the intersecting line while filleting two surfaces, and create a trace while creating a surface. When pushing the digital pen on a curve, the closest point of the curve is selected as the origin of working plane, the X-axis and Y-axis of the working plane are vertical to the tangent line of the point, as shown in Fig.10; when moving the digital pen, the working plane will be moved along the curve. Similarly, a surface is also selected as the working plane, as shown in Fig.11, the stroke sketched on the screen is actually drawn on the surface selected, when delete gesture stroke is drawn on the surface, the surface is deleted and the spatial curve is created.

![Image of Locating on a Curve or Surface](image)

Figure 10. Locating the working plane on a curve.
Summary

The free-hand sketching and the gesture commands have become the main part of a sketching system in the conceptual design at the early stage of automotive styling. In order to meet the habits of stylists, the coordinate system and the working plane can also be functioned more suitable for the free-hand sketching. It is able to not only control the perspective view by three strokes sketched, but also can manipulate the working plane by gesture commands and the moving the digital pen, which make the free-hand sketching more nature and easier to use. The methods have been prototyped in the AutoSketch system, a plug-in software in ThinkDesign. The test results demonstrate that they all work well and give the fresh and novel methods that differ from the traditional ones.

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References


