Doodle Space: Painting on A Public Display by Cam-phone

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ABSTRACT

In this paper, we present a novel interactive application on public displays, Doodle Space, which allows multiple participants collaboratively painting 3D curve on a projected wall using personal camera phones. An image sequence based algorithm is used to estimate the movement parameters of cam phones. Users' cam-phone holding hand's gesture is recognized and monitored in real time which allows users to control a virtual brush naturally by moving their phones in the air. A wireless transmission mechanism based on Bluetooth protocol is implemented to build movement parameters transmission channel between phones and server PC. A 3D drawing scheme is designed to construct 3D curve with movement parameters on the display. People could not only doodle but also manipulate their doodles by dragging, rotation and zoom which are indispensable for true drawing. User studies are applied to testify and improve doodle space's feasibility and entertainment.

Categories and Subject Descriptors

H.1.2 [**User/Machine Systems**]: Human factors, Human information processing; H.5.2 [**User Interfaces**]: Graphical user interfaces (GUI), Interaction styles (e.g., commands, direct manipulation), User-centered design; H 5.m [**User Interfaces**]: Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors, Design

Keywords

Public display, Interactive art, Cam-phone interaction, Doodle, Multiple users, Motion estimation, Bluetooth

1. INTRODUCTION

Mobile phones have become an indispensable part of our daily life. Especially recent years, the functions of mobile phones are not yet restricted to calling or SMS but spread into every single aspect of human life. The computing performance of mobile phones has developed significantly. What's more, smart phones are also equipped with sensors, like cameras and accelerometers [6]. Hence mobile phone is more likely to become a kind of pervasive computing device [6] which is both prevalent and functional. On the other hand, camera phones are already popular and pervasive [21] for years. That makes it possible to use mobile phones in more complex and interesting interactions such as interactive art like Doodle Space without requiring additional sensor configuration.

On the other hand, we have witnessed a phenomenal growth in the usage of public displays recently. Large projection displays and video walls are increasingly seen in public space like shopping malls and airports worldwide [20]. While the research of public display interaction goes deeper and deeper, researchers have been updating interaction technologies all the time. Many interaction approaches have been used in practice such as audio move drama, sound spot and touchable screen. And some guidelines and concepts have been extracted from the research results, which points out that designing interaction in public spaces may focus

on three main points: bodily movement, communication and staging interactive content, public spaces as domain [8]. All these principles are guided our design work.

For the two availabilities of smart phones and the popularity of public displays interactions, we envision a ubiquitous application paradigm in which people can easily access public displays with their cam-phones. To explore more details, we build the Doodle Space application, aiming enabling multiple users simultaneously doodling on public space by moving their cam-phones. Using public display as platform of ideas exchanging, Doodle space can express users' inner world in some extent and doodling collaboratively can promote users to communicate emotionally which finally help people know each other better. Comparing to previous works, our design combines following advantages: 1) nature interactive capability: users could use their hand's natural movements for interaction without any extra learning efforts. 2) high accessibility: nowadays the cam-phones are easy to access 3) easy deployment: users only need to install a client software on their mobile phone;. 4) remote manipulation: people could doodle on the large public display which may be far away.

2. RELATED WORKS

Using human being's natural movements as interaction methods have been catching many researchers' eyesight, which is also one of our work's motivations [8,18,19]. DanceSpace [18,19] is an interface developed by researchers in MIT Media Lab, which renders multicolored graphic trail as well as music according to person's movements tracked by the person finder system Pfinder [22] . Body Brush [5] considers the human body as a whole into a dynamic brush. Through the infra-red illumination motion capture system, the system could detect human body's space motion. Based on the systematic study of the relations between the human body movement and the visual art language, the system finally converts the motion into a rich variety of visual forms and space.

Besides the body movement, hand's natural motion has also been researched to use in the human computer interaction. Small and Ishii [16] give us the idea that using hand's movement in real physical space to navigate in the digital information space. There are too many works on recognizing the hand's motion or gesture that makes it almost impossible to have a full view of the previous works. According to whether they detect full 6DOF of 3D motion or just part of it, we divide them into two categories. The first category is able to fully recognize the 6DOF of the hand's 3D motion. One example is Schlattmann[13] designed system. The system consists of three cameras which are fixed at different positions to observe the hand. The advantage of it is: no time-consuming per user calibration is needed; it is real time. However, the disadvantages are that the system use more than one cameras and the human hand must place at certain domain in order to let the cameras observe. The other category is only recognizing some of the 6DOF at a time [2,4,10,15,17,21,23]. These systems include "The lean and zoom system", "IseeU", "Li and Tang", "Melib". Although these methods could not generate the full six 3D dimensional parameters, the systems only use one camera, which is available to most modern smart phones, and what's more, the algorithm is real time. Melib [12] belongs to the second category on which our work based.

Although mobile phone may have increased the frequency of social contacts, it has not done enough to bring additional meaning in social interaction [19]. By studying the multi-user interaction on a public display, some researchers [6] find out that social interaction is a strong motive to attend a multi-user service, and it is influenced by three factors- context, communication and identification. On the other hand, public display interaction encounters a phenomenal growth [9,14]. Based on these guides, we create the doodle space for multi-users to change ideas by doodling on a public display.

3. System Architecture & Implementation

Doodle Space follows a client-server model to implement an architecture containing several mobile phones as clients and one workstation as server. The mobile phones use image based tracking algorithm to analyze the image sequence captured by the built-in camera so that they can estimate their movements. Once the phones have calculated the movement parameters such as translation, zooming in/out and orientation they can use Bluetooth channel to transmit those parameters to the server. Every single phone is assigned to a unique channel to ensure there is no communication confliction. Whenever the server receives parameter from phones it will proceed some signal processing and parse the signal to classify the signal by the source where they are from. After the processing and parsing procedure, the server can draw 3-D objects using the movements parameters gained from phones. Those 3-D objects will appear on a large wall in front of phone users via projector as shown below.
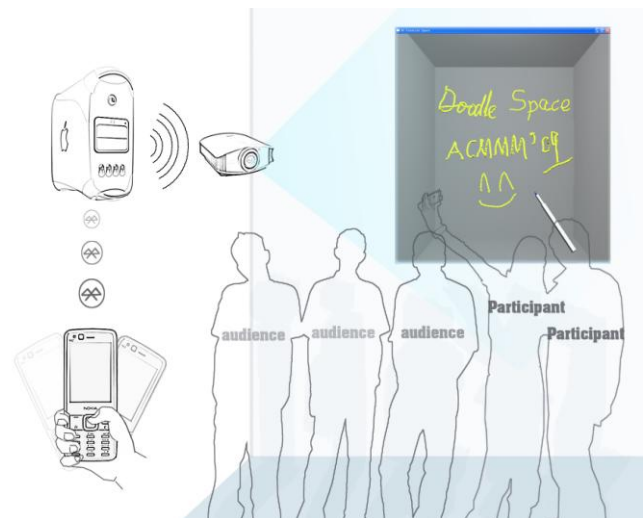

Figure 1. Doodle Space System Architecture.

Our primary implementation platform of client is the NOKIA N82 camera mobile phone which can capture image at a resolution of 640x480 pixels, at a rate of 30 frames/sec, but any phone with Symbian S60 3rd Operation System should be able to run the client application. And our primary server platform is a PC which has a graphic card supporting DirectX 3D and a built-in or external Bluetooth adapter.

3.1 Movement Estimation

Motion estimation algorithm is the technical basis of this project Doodle Space. We have investigated several kinds of technologies such as image based tracking technologies, accelerometer based motion sensing technologies and infrared ray reflection based motion capture technologies. We have chosen optical image sequence tracking algorithm because camera is the most widely used as built-in device in mobile phones and it can capture high resolution images which means the algorithm we chose can be easily used on mobile phone to extend its usability. And the camera based algorithm has some advantages than other sensors which satisfy our application's need well, it can be easily used in common environment without requiring special configuration as long as it's not completely dark, and it is less susceptible to interference than infrared ray device. Comparing to accelerometer, camera based algorithm can sense motion with constant velocity much better. Those advantages make it possible to calculate real-time locations of multiple users' phones accurately without doing integral which may magnify error. But image based tracking technologies may cause battery problem because the camera works at a much higher power level when capturing images than idle time. So we only turn on the built-in camera on when the mobile phone is connected to a server and keep it off when disconnected.

In Doodle Space, we have used a framework named Motion Estimation LIBrary[18](Melib for short) to detect the motion of the camera built-in cell phone. This framework enables the user interface to be controlled by the motion of the user's hand, and the algorithm consists of five major steps: feature block selection, block motion estimation, outlier analysis, global motion estimation, motion filtering [7]. As shown in figure 2, through the steps list above, the algorithm can analyze the input frames and estimate the motion and position of mobile phone with the camera built-in [7].
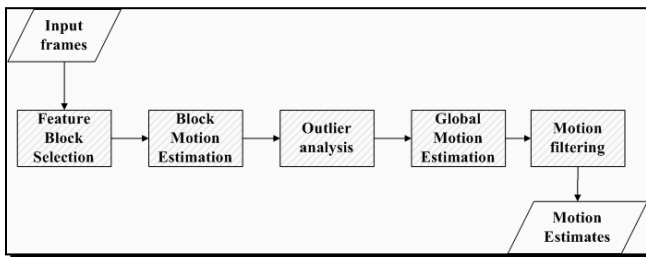

Figure 2. Overview of Melib.

When using the algorithm, there are some parameters need to be set in advance, first we should set the width and height of input images in pixel, second we need to set the amount of feature blocks per column which is equal to blocks per row, third we should set the side length of square feature blocks in pixel, fourth we need to set the motion estimation range in pixel.[7] Considering the limited computing and battery resources on the mobile phone, we set motion estimation algorithm's input image size to 160x120, block amount to 3x3, block size to 6x6 and motion estimation range to 12 pixels in Doodle Space after experiments and comparison.

The output motion and position estimation parameters are formed into four float numbers representing translation along the x-, y-, and z-axes, and rotation around the z-axis. The coordinate system is relative to the mobile device as figure 3[7].
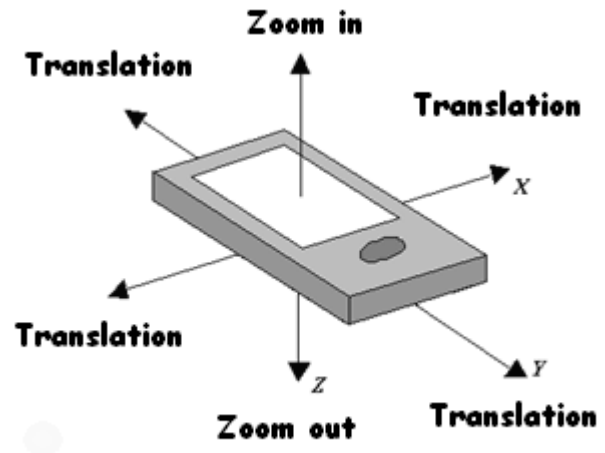

Figure 3. Phone coordinates system.

3.2 Signal Transmission and Processing

Once the mobile phone has calculated its movement parameters, it transmits the parameters to server. To accomplish this task, we have used Bluetooth technology because it's reliable, efficient and commonly built in mobile phones. There are two main difficulties to overcome during the signal transmission. First is that the platform of server is different from client. Second is to support multiple client transmission correctly and efficiently under the bandwidth limit of Bluetooth technology. After receiving signal from clients, the server needs to parse the signal to distinguish users' identifications and apply some signal processing approach such as motion parameters filtering and normalization to satisfy the drawing application's need.

3.2.1 Signal transmission

Considering the clients and server are based on different platforms, it is not possible to transmit message via existing methods, so we must design transmission mechanism by ourselves using Bluetooth protocol. It must ensure that the server can receive correct parameters from clients and since the transmission bandwidth is narrow (usually tens of kilobytes per second) the message packages should be as concise as possible.

First of all, we must build transmission channel between client mobile phone and server PC so that they can send and receive data. To achieve this target, a Bluetooth server is started to listens for an incoming connection request from client. When a connection request arrives, one PC's port is employed to charge the data transmission. Once a connection is built successfully we can assign a COM port to the connection and simply construct a virtual file combining with the COM port. Then client and server can send and receive data from each other by reading and writing the file.

After the Transmission channel built successfully, it is necessary to design an efficient package structure to contain the parameters to be transmitted. Since the COM port transmission is based on byte flow we have designed a package shown as figure 4, using the first byte to store the phone button status, second byte to store the code of button which is pushed, and 4x4 bytes to contain the four output parameters of motion estimation algorithm. This package structure can guaranty message's completeness and correctness costing least bandwidth.

Char: Button Status	Char: Pushed Button's Code	Float: Tran-X	Float: Tran-Y	Float: Tran-Z	Float: Rotate-Z

Figure 4. Package structure.

3.2.2 Multiple user supporting
Supporting multiple Cam-Phone users to work at the same time is one of the advantages of Doodle Space. To implement this feature, the signal transmission layer must have a efficient and reliable mechanism to transmit multiple user's parameter at the same time and distinguish different user's identification. Based on the transmission solution described above, we have designed several scheme and applied them to some experiments which leads us to our final solution. It is simple but functional.
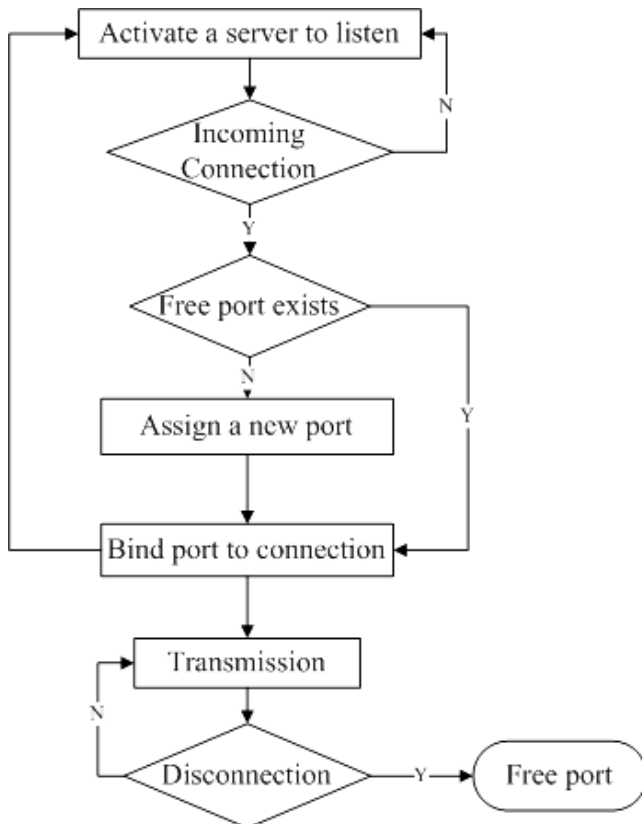

Figure 5. Flow chart of multiple user solution.

As discussed in 3.2.1, we use COM port to send and receive data between client and server. Our solution is to assign each client a unique COM port to transmit signal so that there will be no communication confliction and server can simply distinguish clients' identification via the COM port number. This solution can reliably support multiple clients to simultaneously transmit data with server without bringing additional burden to system. And in practical experiment it works well.

As figure 5 shows, we have implemented a flow of the solution to ensure that the system uses least COM port when running by freeing COM port assigned to disconnected device and retrieving free COM port before creating new one.

But this solution has two limitations. First, every time we set up the system, we need to manually configure a number of COM port since current Bluetooth API do not support programmatically creating COM port which may be available in future [3]. Second, the Bluetooth server only supports up to five COM port combined to connection as local service which means the system support at most 5 users currently [3], this limitation may be overcome by extending current solution to allow several users transmitting through one channel when the port limitation is reached and clients sharing channel should send flag bytes representing their identification in message package so that server can distinguish signal's source by recognizing the flags associated with port number.

3.2.3 Filtering and Normalization
After server parses the signal and distinguishes them by user's identification, there is one more procedure before deliver the parameters to application layer which is signal processing. This procedure consists of two major steps: 1. Signal filtering. 2. Parameter normalization.

Signal filtering is applied to original parameters received from Cam-Phones to reduce the noise impact and improve interaction experience. First a high-pass filter is applied to eliminate the accidental slender movements, and then a motion classifier is presented to reduce interference between translation and zooming.

Normalization is necessary to supply eligible drawing parameters to application layer because the output parameters of motion estimation algorithm are not in the same form. The translation along x- and y- axes is given by the pixel movement between two frames while translation along z- axes is given by the ration of two adjacent frames' size. So we adopt the formula below to transform the z- axes translation so that application layer can use all translation in the same way.

$$\begin{cases} z = \text{sc-}1; & \text{sc>=}1 \\ z = \text{-}1.0\text{f/(sc)+}1; & \text{sc<}1 \end{cases}$$

3.3 Design on Server PC
The server software of Doodle Space is running on the server PC. The server PC needs a Bluetooth adaptor to get the information of spatial movements of cam-phone. The Cam-phone's movements are represented in three-dimensional coordinate (X, Y, Z). (X, Y) is locations in the 2D plane and Z stands for the depth information. While waving cam-phone left and right or up and down, (X, Y) could well represent the cam-phone's location. While pushing or pulling the cam-phone, Z is changing to reflect the depth's

information so as to make sure the painting curve is 3D dimension. DirectX is required to run the software and render doodle pictures on server PC.

In Doodle Space, every client has a controller, which appears as a pen or a hand, to draw in doodle space according to the relative movement of cam-phone. The server PC reads the three-dimensional coordinate movement information of each cam-phone from the Bluetooth port every 0.1 second, and renders the data as the curve in doodle space.

To present freely and easily drawing experience for users, Doodle Space provides two modes for users to draw: Paint Mode and Edit mode. In Paint Mode, users could draw curves by waving their cam-phone in the air. In the Edit mode, rotation and scaling are provided for users to change the perspective of view and magnify (or shrink) the curves. Phone buttons are employed to switch between two modes. Users can also press phone buttons to select the detail function of each mode.

3.3.1 Paint Mode
In paint mode, users can draw naturally in Doodle Space. There will be a pen, which stands for cam-phone in Doodle Space (shown in Figure 6).When a user moves the cam-phone, the pen moves synchronously in Doodle Space. A 3D curve that represents the movement of cam-phone will be left on canvas.
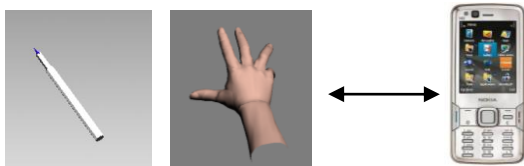

Figure 6: A pen stands for the cam-phone in Paint Mode and a hand in Edit Mode

The painting curve is based on a model of joint-bone, which comes from references of bones system of 3DS Max [1]. We set joints at the locations of the data which read from the Bluetooth port every 0.1 second, and connect adjacent two joints with a bone. The server software alternately renders joints and bones, and then we get a complete curve. Interpolation is used between two joints in order to smooth the curve.

In Paint mode, we also provide different colors and textures for users to pick freely. Wherever users paint or pause, they can change color and texture. When users make the change, the new part of sculpture will present as new color and texture while the old part keeps unchanged. In this case, we provide two kinds of color, blue and yellow, to chose. Each user can change the color of the following curves.

3.3.2 Edit Mode
In edit mode, users can edit the curves. A hand appears on screen instead of the pen to give users visual feedback of editing. After changing from Paint Mode to Edit Mode by pressing the button, each user could edit the own curves by moving cam-phone which is similar to the paint mode.

There are three functions in Edit mode: translation, rotation and scale (shown in Figure 7). Translation changes the location the whole curves and is a basal function of drawing pictures in any case. Rotation changes the perspective of viewing and is a key-

press trigger function to show and present the 3D curve, which make Doodle Space different from 2D painter. Scaling is a kind of specialty of virtual objects.
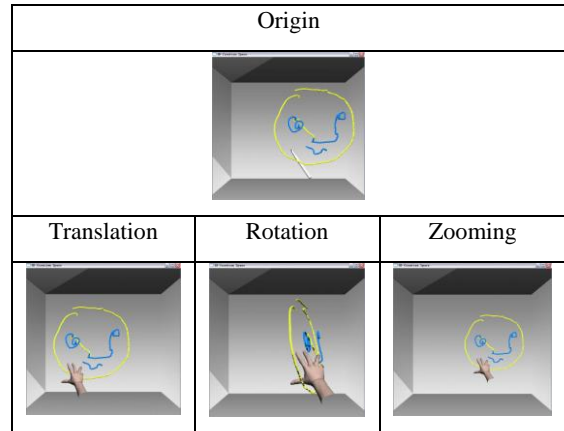

Figure 7：Performance of edit mode

3.4 Design Features
Doodle Space combines practicability and entertainment together. The design approach of Doodle Space takes the occasion of its application, target customers, its main features and the auxiliary assistance into consideration, which extracts to the following four points, as the design features of Doodle Space.
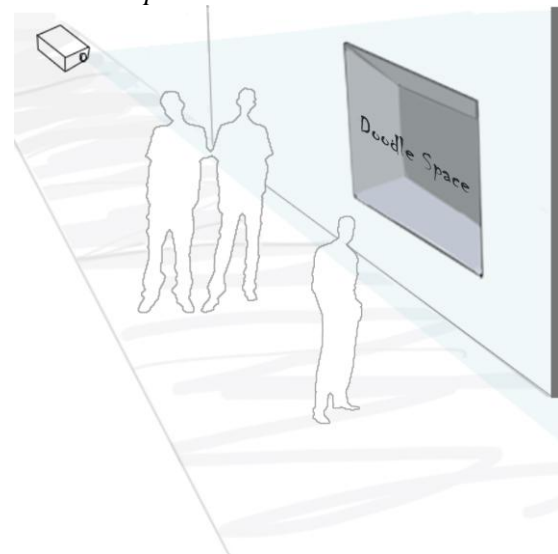
3.4.1 Public Space

Figure 8: large public display.

We want Doodle Space to be installed in a public space for people sharing pleasure and exchanging ideas. A large display device, like a projector or a big screen, is required to be set on public space for Doodle Space (shown in Figure 8). Both participants and audience can see the rendered picture together in one display device. We want people, who do not know each other, can join into Doodle Space which becomes to be a communicate bridge. Public Space also provides participant enough room to draw 3D sculpture in air.

3.4.2 Multiple Participants

In Doodle space, users can collaborate to create one painting or simply doodle on their own. Currently, the system supports at most five users to paint simultaneously without conflict and hence (shown in Figure 9).

Multiple Participants is independent of each other. An audience can be a participant by joining Doodle Space with the own cam-phone. There may be overlap between 3D sculptures from different users, which attributes to sharing display device. However, one user paint or edit his own sculpture, which has no impact on others operation or 3Dsculpture. The Users can work together to complete the common task or just solo by each other, which depends on their own Subjective idea and action.
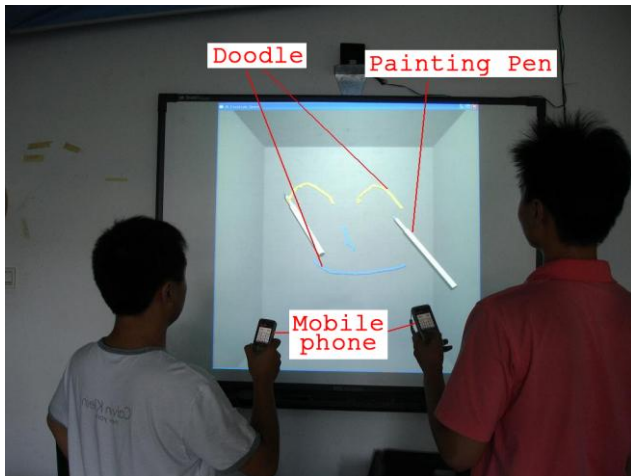

Figure 9: Multiple participants are drawing together

3.4.3 3D Painting

Compared to conventional 3D input methods and 3D modeling techniques, Doodle Space is more natural and amicable (shown in Figure 10). Doodle Space broke the traditional two-dimensional input device operating restrictions.
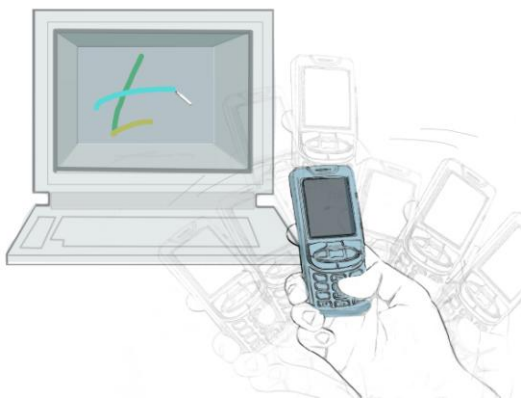

Figure 10:3D movement correspond with3D sculpture

In Doodle Space, people use their hand's movement as the brush to paint. Both artists and common users can be well inspired, enjoy free doodles, and paint beautiful 3D drawings.

3.4.4 Design of Assistance

Doodle Space brings out a new kind of experience of drawing. Assistance is required to help users operate smoothly and comfortably. Besides tips shown on mobile screen, user can also get assistance from the public display. User can call 3D reference points in display space (shown Figure 11). The points help users get the position of brush and sculpture in 3D virtual display space. The reference points also guide users to the right direction, which can avoid the mistake, which comes from 2D canvas showing 3D picture.
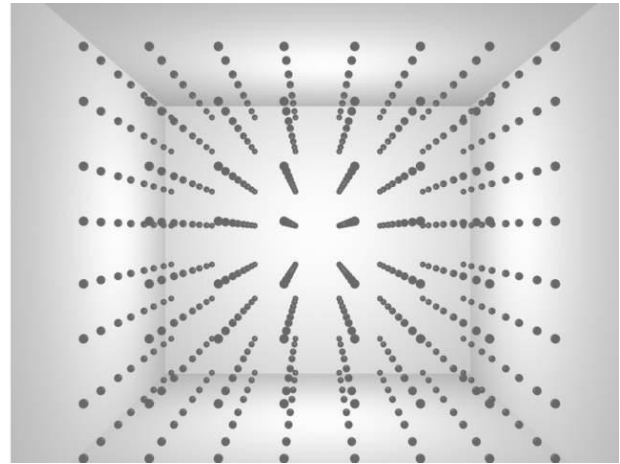

Figure 11: spatial assistant reference points.

4. User Experience and System Improvement

The recommendation and feedback from users have promoted the development of Doodle Space. The embryonic form of Doodle Space has two parts: the recognition and test of 3D movement of cam-phone; drawing 3D sculpture in PC with traditional input devices. And then we integrate these two parts together to be 3D brush based on mobile movement. This is initial stage of Doodle Space. We use it to take a lot of step-by-step test. Meanwhile we add features into and patch details constantly. We advanced step by step by researching the feedback and considering the recommendation from suitable test. User experience is an important component of system improvement.

4.1 Participants

We invite seven subjects, including three professional art teachers, three computer science background graduates, one art background graduate to take the user experiments. Five of them are untrained users so that we can well test Doodle Space's feasibility. Operation without additional costs and easy learning are main features of Doodle Space.

At the beginning of user study, we explain to users how to carry out basic operations and show a simple model. Most of the test users, who are engaged in the work of art, can imagine a 3D graphics in air and try to draw it directly through 3D motions. The artists consider Doodle space a very interesting and useful system. They reflect that they can create 3D model more intuitively and freely and more importantly point out kinds of problems they encountered which help us give the following improvements.

4.2 User Experience and Feedbacks

User experience and feedbacks point out previous Doodle Space's three flaws. We figure out these problems by taking these feedbacks into consideration.

4.2.1 Drawing Reset

At the initial stage of Doodle Space, when a user moved the cam-phone, the pen would draw the curve ceaselessly. In case users move cam-phone to uncomfortable position, they can't pull the cam-phone back to suitable position without having an impact on the work already. And sometimes the users paint careless mistakes. The function, which can provide reset action, is called for Doodle Space.

For this reason, we have added drawing reset function, which contains two independent parts: pen relocation and curve clear. In pen relocation mode, the pen in Doodle Space still moves with cam-phone motion, but there will be no new curve follow the pen. Users can position the pen as expected, and then restart to draw. Curve clear can remove shown curve, and users would be back to the initial state, which is ready to begin to draw a 3D curve.

4.2.2 Mobile Display

For a new user, we tell him function and usage at beginning. However, most of users cannot clearly remember all the features, so that the trainers have to explain again and again. The users wanted instructions function, through which themselves can learn how to operate.

Mobile screen is capable of achieving assistant instruction. We note the function menu displayed on the mobile phone interface (shown Figure 12). While carrying the cam-phone the side of reading the screen, users can get the information of functions of mobile buttons.

Figure 12: Mobile Interface: key pressing hints for users

4.2.3 3D Rotation and Scaling

At first, control method of rotation and scaling is similar to Traditional software mouse operation. Users reported that rotation and scaling operated like a mouse, but less accurately. By use of advantages, we designed an approach of rotation and scaling based on the 3D movement.

Method similar to the mouse operation: The use of information of relative movement of x-axis and y-axis achieves rotation. When users select to scale curves, scaling parameter depends on the data of z-axis. Using only one or two axes of information, this method is similar to state of mouse. However, Accuracy of cam-phone's movement targeting is poor than moving mouse's. Specifically in the case of shooting long distance, like 3 or 4 meter, vision, the effect of scaling is very small, when users move cam-phone the same length.

Edit mode based-on 3D information: The main feature of Doodle Space is 3D input. We use the changes of 3d location, pen relative to center of curves, to rotate and scale curves, which can get a better effect. Figure 13 is a theory Schematic: Black curve stands for the 3D curve. Point C is the center of the curve. Point A is the last location of pen, and point B is current. When a user rotates the curve, rotation angle is angle ACB, rotation axis is normal component of plane ABC. When a user scales the curve, scaling coefficient is quotient of length2, the length of vector CB, divided by length1, the length of vector CA. They are dynamic rotation and scaling. With the same distance of cam-phone moving, the degree of rotation and scaling depends on the direction of moving and distance between pen and center. So that users can operate more subjectively. Meanwhile, the drawbacks of scaling have been improved effectively.
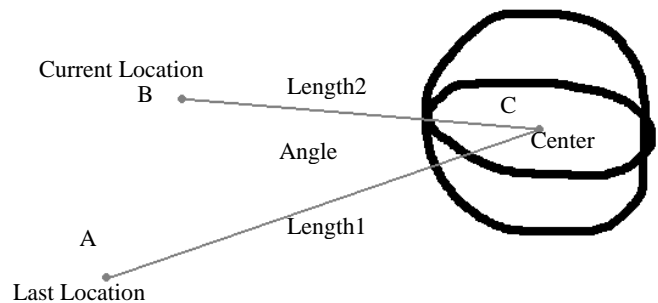
Figure 13: 3D edit

5. FUTURE WORK

We intend to continue to improve the Doodle Space through interaction design, basic technology and systematic testing three directions. We hope that Doodle Space can be applied to more specific aspects of the artistic creation or entertainment in the future.

3D painting is a form of virtual graphics, which is similar to the actual drawings or sculpture. To make use of the advantages of 3D painting has always been our core design concept. We feel that cooperative or competitive multiplayer interactive graphics is the key point of future design. And the texture and color should be richer. Stone and metal materials may be considered as new option. We hope that doodling can become creation with all the improvement.

In order to increase the accuracy of 3D painting, we are working on improving movement estimation algorithm and employ more sensors. We fill that to distinguish rotation and translation better and get more accurate and detailed data of the zooming motion is important through user studies. So we are trying to design our

own algorithm rather than leveraging open source library. We will try to employ one more camera or an accelerometer as assistance to achieve these objectives.

After all, we fell it's important to go through a new rounds of user testing which is more systematic and detailed. The new evaluation model should take the speed, accuracy, quality, comfort, freedom and intuitive of 3D painting into consideration. To evaluate the feeling of interaction, we will concentrate on modeling and compare alternative options.

6. CONCLUSION

In this paper, we designed and implemented a system called Doodle Space that enables multiple participants to use their cam-phones as a brush painting 3D curve collaboratively on a projected wall in real time. User studies guide us to improve the feasibility and entertainment of doodle space. Through the user study we found that 1. Doodle Space can recognize and monitor cam phone holding hands' gesture reliably. 2. Signal transmission between multiple phones and server PC is correct and consecutive under client-server mode. 3. Multiple participants can leave their own scribbles such as plants, animals or even imaged shapes in doodle space which finally form a kind of art. 4. Doodle Space provides participants a channel to express their inner side and exchange ideas with others. 5. Currently the target users of Doodle Space should be average users who have mobile phone experience and with some improvement applied, Doodle Space will satisfy professional designers' need better.

In all, we conclude that by employing camera and Bluetooth the use of mobile phones can go beyond calls into the interaction domain. Participants report that Doodle Space is intuitive, convenient and enjoyable for them to paint in Doodle Space by our interaction techniques. And Doodle Space indeed creates a better chance for people, some of whom may hardly know each other before, to have fun, or even to make friends with each other. What's more, Doodle Space is a pure software project. We didn't make any hardware changes to phones and PC so result of our research is easy to deployment.

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