Bi-Manual 3D Painting: Generating Virtual Shapes with Hands

Alexis Clay
ESTIA
Technopole Izarbel
F-64210 Bidart,France
+33 5 59 43 84 78
a.clay@estia.fr

Jean-Christophe Lombardo
INRIA Sophia Antipolis
2004 Route des Lucioles
F-06560 Sophia Antipolis, France
+33 4 92 38 50 26
jean-christophe.lombardo@inria.fr

Julien Conan
ESTIA
Technopole Izarbel
F-64210 Bidart,France
+33 5 59 43 85 11
j.conan@estia.fr

Nadine Couture
ESTIA, LaBRI
Technopole Izarbel
F-64210
Bidart,France
+33 5 59 43 84 67
n.couture@estia.fr

ABSTRACT
The rise of gestural interaction led artists to produce shows, or installations based on this paradigm. We present the first stages of the Virtual Sculpture project. This project, born from a collaboration with dancers, proposes bi-manual interactions in a large augmented space: we aim at giving dancers the possibility to generate and manipulate virtual elements on stage using their hands. For this goal we developed 3DPainting, which allows generating 3D surfaces with both hands. 3DPainting seeks to engage the user through movement, as well as being a tool for dancers. In both cases, our goal is to provide seamless systems that promote artistic practice. In this paper we present 3DPainting through two systems. The first system is a fully immersive CAVE environment that allows one user to merge its action and perception spaces for creating 3D shapes. The second system features a single screen with back projection and full-body motion capture. This second system is more easily transportable and allows an audience to perceive the created elements. An exploratory evaluation and a comparison of both systems is provided.

Categories and Subject Descriptors
H.5.1, H.5.2 [Information interfaces and presentation]: Virtual Reality, User Interfaces; J.5 [Computer Applications]: Arts and Humanities—Arts, fine and performing.

General Terms
Experimentation, Human Factors

Keywords
Virtual Painting; CAVE; surface generation; digital arts; virtual reality; augmented dance;

1. INTRODUCTION
Since 2006 we developed a strong collaboration with a ballet dance company, developing augmented reality tools and interaction techniques for augmenting a live dance show. The CARE project (Cultural Experience: Augmented Reality and Emotions), which ended in march 2011, aimed at setting up several design tools, interaction techniques and devices to augment a cultural event with emotions. With augmented ballet as one application case, our goal was to augment a ballet performance and to make a dancer interact with virtual elements on stage. This project ended in a staged demonstration that took the form of an augmented show, entitled "CARE: staging of a research project" [9]. We now focus on allowing the user/artist to create 3D shapes, in order to use movement for plastic creation. In this paper, we present the first step of the Virtual Sculpture project: "3DPainting" allows bi-manual creation of 3D surfaces or lines in a large space, without tools. Modeling 3D space in real time is a great challenge nowadays (see 3DUI 2013 conference contest [11]). The section and parameters of those shapes are defined by the hand conformation, and their extrusion by the hand movement. The metaphor is direct: virtual matter seems to be generated right under the artist hand and stays fixed in space. Starting from there, space becomes a blank support where one can paint (see example of results in Figure 1).

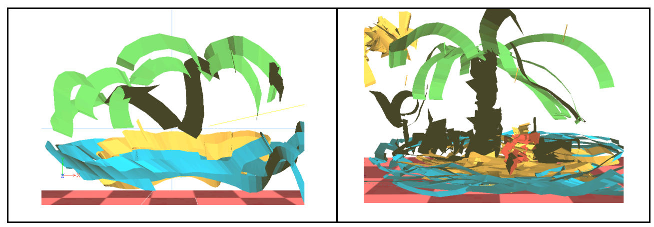


Figure 1. Drawings of a desert island with our system.

We designed 3D Painting with the goal of not restricting the user's movements for the task of drawing, especially as we use it with professional dancers. As such, we focused on manual interactions; the metaphor of extruding surfaces through one's hands shows natural aspects that make the designed interactions extensible to other fields. We developed two systems for 3DPainting and performed an exploratory evaluation with both laypersons and professional dancers, showing the differences, pros and cons of each system, providing us with a first user feedback for future development of the final setup. A 6 minutes video is available on youtube describing our work [10] we advise the reader to watch it before proceeding with this article. *[Note to reviewers: the referred video is enclosed with this article and will be released on youtube if the paper is accepted]*

2. RELATED WORKS
The goal of our system is to allow the user to draw directly in a 3D space. It is not aimed at being a modeling tool (like 3dsMax). Rather, we seek to give the user the ability to sketch in space. Several techniques already exist to draw directly in a 3D immersive environment. Deisinger *et al.* [3] led a CAVE (Cave Automatic Virtual Environment) experimentation on several modeling systems calling three different techniques. The first one is matter creation by "substance" injection on a given point. In this approach, the artist adds volume to matter, and his movement

creates the shape. In the same manner, the BLUISculpt system [2] divides space into voxels, which the artist can paint. The second approach is surface generation. In the system being tested in [3], the artist defines a flat polygon by points in space, and successively attaches created polygons to his sketch. Finally, the third technique, used by the third system in [3] uses automatic surfaces generation from directives curves being drawn by the artist. This principle has been taken back from the FreeDrawer [7] system where the user traces B-splines in 3D space. Deisinger *et al.* noticed several recommendations for designing an ideal sketching tool, which should 1) be a conceptual phase tool towards a certain elaboration degree, 2) hide its mathematical complexity, 3) provides a real time and direct interaction, 4) allow large scale and volume modeling, and 5) be intuitive.

The first two points are more focused on the task of representing ideas, concepts, or early designs. 3DPainting is intended for free drawing (or even doodling) in 3D and is more artistic in its philosophy. That different approach led us to focus on the three last points. As such, we wanted to provide with interactions intuitive enough to let the user focus on exploring and mastering drawing movements and techniques. In our mind, a perfect system would be as simple to use as a pencil, but would require practice and technique to achieve a beautiful drawing. We inspired ourselves from two systems from the literature. Schkolne *et al.*'s SurfaceDrawing [6] allows the user to generate 3D surfaces directly from his hands, using data gloves. 3D display of the generated surfaces is performed by the responsive workbench, a horizontal screen able to track the user's head and therefore display stereoscopic 3D from the corresponding point of view (Figure 2.a). The user wears tracked 3D glasses, allowing the responsive workbench to modify the display according to the user position. The 3D surfaces, created by the user's hand, can be altered through the use of tangible props. Keefe *et al.*'s CavePainting [4], provides several tangible interfaces (brush and paint bucket for example) to allow painting in the volume defined by a CAVE system. The painter can paint strokes in the 3D space where he can stand and move (Figure 2.b). Our Virtual Sculpture prototype merges both approaches, associating freehand interaction with a large enough space to move within for visualization and interaction.

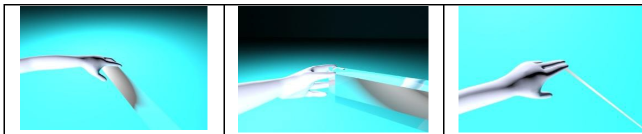
(a) **(b)**

Figure 2. (a). Surface Drawing [4]. (b) CavePainting[3]

3DPainting was initially designed with dance in mind as a visual and interactive tool for choreography: we want a dancer to be able to create virtual scenes while dancing. As the authors were doodling with it for technical testing, it appeared that the combination of a large interaction space and using one's hands to draw engaged even laypersons in exploring full-body movement for drawing, instead of focusing on the visual result. 3DPainting engages the user through movement, in the same way that players can be engaged through movement in [1].

3. INTERACTIONS

Our system aims at providing three interactions, adapted to accomplish three main tasks: drawing a surface, drawing a volume, and drawing a line (see Figure 3). However, only surface and line generation are currently featured in our systems.



a.Surface generation **b.Volume generation** **c.Line generation**

Figure 3. Proposed interactions

The surface generation interaction directly comes from [6] and allows hand surface generation. The hand conformation at a given moment defines the shape of the generated surface. At a time *t*, we consider the wrists' positions and the articulations and tip positions of the middle finger. The curve traced by those points at *t* instant defines surface section at *t*. This section curve is periodically sampled (typically 10-25 times per second). For each new curve record, surface between *t* and *t-1* sections is being generated. Surface generation is achieved by performing a movement parallel to the palm's surface.

The line generation interaction features creating curves or points creation in space. Virtual matter is generated at the end of the middle finger's tip. This allows better drawing accuracy than with the entire hand (like a tinier brush).

In order to switch between modes (line drawing, free movement, surface drawing) we drew a modal interaction from [4]. We use the thumb position to switch between "Draw line" mode (thumb extended), "free movement" mode (no drawing – thumb in a relaxed, middle position) and "surface drawing" mode (thumb folded against the palm). This allows for independent control of each end, triggering bi-manual painting.

Finally, each system features the ability to choose the color for each hand. This was developed differently according to the system, and hence will be described in the following paragraph.

4. HARDWARE AND SOFTWARE SETUP

We built two prototypes for 3DPainting, for two different contexts of use. The first prototype uses a CAVE environment for immersion, and infra-red markers for tracking. In this prototype, the user is fully (though the only one) immersed in the drawing. The second prototype uses a single projective screen, where stereoscopic rendering can be parametered from the user's point of view (as in a CAVE) or from a fixed audience point of view (as in 3D movie theaters). The latter system therefore allows choreographing a 3D painting into a live show, but the user himself is blind to its own creations.

4.1 3D Painting in a CAVE

The developed prototype uses immersive cube (CAVE) from [redacted] Research Centre [redacted] immersive room. Infra-red markers and cameras allow tracking the user's head, wrists, and thumb, index and middle finger's tips in real-time. 5DT datagloves are used to obtain folding of the fingers. To facilitate [redacted] room appropriation by researchers and collaborators, [redacted] developed isiVR, a middleware dealing with developer's ready-to-use tools useful in any immersive applications. Based on OpenSceneGraph openSource render engine, isiVR makes management available for peripheral inputs, display devices, head-tracked stereoscopic render, and synchronized cluster utilization.

This first prototype allows full immersion, but the user is the only one who can see the 3D painting. Wrist and thumb tracking allowed implementing the thumb modal interaction. To generate surfaces, we consider the positions and orientations of the wrist and tip of the middle finger as controls for generating a Bézier curve. This Bézier curve is being used to set up Bézier surface according to hand's movement. The surface is hence defined mathematically instead of being defined by a vertex group, which facilitates data sampling and potentially allows manipulating the levels of detail (LOD) of the generated surfaces. Lines are generated as very narrow surfaces and hence follow the same process. The precision of the CAVE system allowed developing a pointing technique, using the index to select a color in a 2D palette, featuring nine colors.

4.2 3D Painting on stage for an audience

The purpose of this second prototype is to propose a cheaper 3DPainting prototype, both for a single user and for use in a choreographed process in front of an audience. As such, the stereoscopy can be calibrated for the user's or an audience's point of view. Tracking is performed with an XSens MVN motion capture suit [8] coupled with 5DT datagloves [8]. Those devices are more intrusive and less precise than the CAVE's IR sensors but allow for a much larger interaction space and are transportable. We developed and use custom blocks in Virtools software [8] to handle interactional and graphical aspects of this second prototype, coupled with NVidia glasses for stereoscopy [8]. A single rear projected screen (3.5mx2.5m) is used for stereoscopic projection. Independent cascade palettes for each hand were also developed; closing the fist on one hand makes the corresponding palette appear. Moving the fist allows choosing the color, and opening the hand completes the selection. Only 6 colors are available in these palettes, and choosing a color requires more movement (i.e., moving an arm and/or the basin as opposed to pointing a finger) than with the CAVE prototype.

5. USER EVALUATIONS

We first conducted an exploratory user study with four laypersons, and then with two dancers as experts in space evaluation and manipulation.

5.1 Evaluation from laypersons

In the first evaluation, four equipped people (2 men, 2 women, age 23-41) tested the on-stage prototype. Two subjects had previously used the system, and two were novice users. In an exploratory learning mode, subjects were first asked to draw basic geometric figures (circle, square and triangle) as a first try. They were then asked to draw 1) the Disney logo (a single-stroke Mickey head silhouette), 2) a desert island, and 3) a tunnel that surrounded them. In 2), the goal was to draw a full landscape; in 3) the goal was to create a scene fully surrounding the user. Users were then asked to rate each drawing on a 6-step scale, and to rate (on a scale from 1 to 4) the emotions they had experienced during the test on the Genova emotion wheel [4]. An observer also rated each creation. The analysis of evaluation results shows that subjects were mildly happy with their creations; their rates matched the objective ratings (means resp. of 3.7 and 3.8 over 6). It was difficult for the users to draw and to see where they were in relation to the virtual space. In the light of the authors' experience in the CAVE system, we hypothesize that these difficulties are mainly due to hardware restrictions. In the tested prototype, the tracking system lacks precision (errors of ~10cm may occur on each hand). Furthermore, a single screen greatly limits the field of 3D vision, thus sometimes breaking the illusion of stereoscopy. The CAVE system is much less intrusive, more precise, and offers a full volume for immersion, and proved much easier to use for the authors.

First-time users tended to look at the screen, constantly referring to it, and produced 2D drawings. More experienced users of our system used the whole space to produce 3D drawings, and relied more on their own perception of where the virtual objects should be, only referring to the screen as a punctual feedback. All users, however, pointed the experience as very pleasant. "Interest" and "Satisfaction" were highly rated by all (scale of 3 or 4), and "Joy", "Exaltation" and "Surprise" by 3 out of 4 subjects. One subject experienced a mild feeling of anger (2) as the system did not respond well enough. Overall, users tended to occupy more and more space as they were getting familiar with the system, and began to create specific movements for details (e.g. the trunk of the palmtree as in figure 1).

5.2 Evaluation from dancers

We aim our systems to be used for augmenting a live dance show. As such, we asked two dancers to try them. One tried the CAVE system (dancer A), and the other the on-stage prototype (dancer B). Both subjects were asked to perform an improvised dance. A quick interview was conducted afterwards. Dancers are accustomed to analyze their movement, both internally and in relationship with the space they move within. As such, dancers are very interesting verbalizers when it comes to comment on an experiment. Both dancers were enthusiastic after trying the two prototypes. They did not intend to draw, but rather explore how their movements were transcribed as 3D strokes.

Dancers were asked if they felt limited by the hardware (intrusiveness of the tracking devices and limitation of the interaction space). In the CAVE environment, dancer A had a light tracking system and danced in a walled 3mx3mx3m box. In the on-stage system, dancer B had a rather intrusive tracking system but the space within which he could move was not confined. Both stated that such constraints could be burdening (it was the case with the intrusiveness of the motion capture system for dancer B), but that those constraints nourish the creativity by setting up specific parameters for movement. Dancers were then asked about the responsiveness and accuracy of the system. This proved a more important factor than intrusiveness. Dancer A was very enthusiastic, spontaneously (we did not ask for a note) giving an 8/10 to the CAVE system, his only concern being the difficulty to manage the thumb position while dancing. Dancer B, on the contrary, felt more frustrated with the lack of precision of the on-stage motion capture system, as he felt he was not always

Table1: Some comparisons as a guide for further improvements

	LARGE SCALE MODELING	IMMERSION & MERGING ACTION/PERCEPTION SPACES	TRANSPORTABLE & ALLOWS AUDIENCE	STEREOSCOPIC RENDERING FOR PAINTER	STEREOSCOPIC RENDERING FOR AUDIENCE	ENGAGEMENT	DRAWING LINE & SURFACE	REALTIME & DIRECT INTERCATION	COST	INTRUSIVE FOR PAINTER	PRECISION	USABILITY & PLEASANT
CAVE	+	++	- -	++	- -	++	+	++	- -	-	++	++
ON STAGE	++	+	++	+	+	++	+	+	+	- -	+	+

in control of what was rendered on screen. Finally, we asked both dancers what was their relationship with the virtual strokes when they were dancing. Dancer B stated that "3D painting reveals the shape of movement in space. It shows that movement is not only an abstraction, but is also a form and a description of space. It is extremely interesting for choreography". Dancer A's first reaction was similar, as he saw in the strokes a trace of his own movement. This led him to focus on it at first, trying to obtain beautiful lines; after a while, he tried to take his attention off the strokes, focusing on his own movement, and only checking punctually on the visual display. We relate that to the evaluation from laypersons, where first-time user would constantly refer to the graphics whereas more experienced users would rather concentrate on movement and use them as a punctual feedback.

5.3 Discussion

The evaluations that we conducted are preliminary and were not designed to validate our system as such, but rather have a preliminary feedback (both from laypersons and dancers) and point out the key improvements that should be made to our systems. It also allowed us to witness some recurrent behaviors among the users, and to obtain deeper feedbacks from the dancers. Both dancers are also choreographers (as a hobby for dancer A, and in a professional frame for dancer B). And as such could give valuable comments on how to use our systems for choreography.

The two systems, although designed for 3DPainting, bear differences of their own (see Table 1). The CAVE system benefits from better tracking equipment and full immersion, and provides a much better single user experience. The on-stage system suffers from less precise tracking and limited projection surface for now, impairing the overall experience. These issues can be tackled with today's motion tracking technologies, and by adapting isiVR to a stage setup.

Our preliminary evaluation gave us promising feedback and directed us towards the following hypotheses. First, full-body movement engages the user in the experience of drawing. Second, the featured interactions allow the user to focus on and explore his movement to practice his drawing techniques, making gradually better use of space, and discovering subtleties with the system, showing its generative power. Future works will consist in evaluating those hypotheses. Feedback from the dancers confirmed the interest of 3DPainting for dance and choreography. Even without actively trying to create a graphic scene, the persistence of movement brought by the 3D strokes is an interesting proposition to be brought upon an audience.

6. CONCLUSION

We developed two prototypes for bi-manual 3D painting. The CAVE prototype is fully immersive, allowing precise generation of 3D surfaces, and an overall better single user experience. The stage prototype allows the presence of audience and deployment in several contexts. Laypersons and dancers/choreographers were asked to test both systems in an exploratory experiment, showing the interest of our systems and giving us some leads for improvement.

In the short term, our future works consist in three points. First, we need to improve the accuracy of the on-stage system. Second, we will conduct more thorough user experiments, using both laypersons and dancers, to validate both systems both from a technical and user experience point of view. Third, in the frame of our long-standing collaboration with a National Choreographic Center (Malandain Ballet Biarritz) we aim at producing a show using our on-stage prototype in December 2013, implying an error-free functioning of our prototype. Longer terms goals involve development of volumic drawing with the hands and providing algorithms and interactions for editing the drawings.

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8. REFERENCES

[1] Bianchi-Berthouze, N. (2011). *Understanding the role of body movement in player engagement*. Research report. UCLIC, University College London.

[2] Brody, B., Chappell, G.G. and Hartman, C. 2002. BLUIsculpt\™. In *ACM SIGGRAPH 2002 conference abstracts and applications* (SIGGRAPH '02). ACM (2002), New York, NY, USA, 291-291.

[3] Deisinger, J., Blach, R., Wesche, G., Breining, R. and Simon, A. 2000. Towards immersive modeling – challenges and recommendations: a workshop analyzing the needs of designers. In *Eurographics Workshop on Virtual Environments* (2000), 145-156.

[4] Keefe, D. F., Feliz, D. A., Moscovich, T., Laidlaw, D. H., and LaViola, J. J. 2001. CavePainting: a fully immersive 3D artistic medium and interactive experience. In *Proceedings of the 2001 Symposium on interactive 3D Graphics* (I3D '01), New York, NY, 85-93.

[5] Scherer, K.R. 1984. Les émotions : Fonctions et composantes. *Cahiers de psychologie*, 4, 1, 9-39.

[6] Schkolne, S., Pruett, M., and Schröder, P. 2001. Surface drawing: creating organic 3D shapes with the hand and tangible tools. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Seattle, Washington, United States). CHI '01. ACM (2001), New York, NY, 261-268.

[7] Wesche, G. and Seidel, H.P. 2001. FreeDrawer: a free-form sketching system on the responsive workbench. In *Proceedings of the ACM symposium on Virtual reality software and technology* (VRST '01). ACM (2001), New York, NY, USA, 167-174.

[8] www.xsens.com, www.5DT.com, www.virtools.com, www.nvidia.com

[9] "Care project : Staging of a research process" video: http://www.youtube.com/watch?v=Bbl0CxFcUZw

[10] Bi-manual 3DPainting, video for this article: XXXXXXXX

[11] 3DUI 2013 Contest : http://3dui.org/cfp-3dui-contest