# MAI Painting Brush: An Interactive Device That Realizes the Feeling of Real Painting

*Mai Otsuki, Kenji Sugihara, Asako Kimura, Fumihisa Shibata, and Hideyuki Tamura*
Ritsumeikan University
1-1-1 Noji-Higashi, Kusatsu, Shiga, Japan

**ABSTRACT**
Many digital painting systems have been proposed and their quality is improving. In these systems, graphics tablets are widely used as input devices. However, because of its rigid nib and indirect manipulation, the operational feeling of a graphics tablet is different from that of real paint brush. We solved this problem by developing the MR-based Artistic Interactive (MAI) Painting Brush, which imitates a real paint brush, and constructed a mixed reality (MR) painting system that enables direct painting on physical objects in the real world.

**Author Keywords:** Painting system, mixed reality, input device, paint brush, brush model, brush stroke.

**ACM Classification Keywords:** H5.2 [Information interfaces and presentation]: User Interfaces. - Haptic I/O, Interaction styles, Input devices and strategies; H5.1 [Information interfaces and presentation]: Multimedia Information Systems - Artificial, augmented, and virtual realities.

**General terms:** Design, Human Factors

**INTRODUCTION**
The field of computer graphics has seen remarkable progress in the recent times. Many drawing and photo-retouching software packages have been developed as a result of non-photorealistic rendering research projects [1]. Quality digital painting software allows users to create realistic water or oil paintings; it is now widely used by professional artists and designers as well as amateurs.

In such digital painting software, a graphics tablet and a 2D display are used as input/output devices. However, some users prefer direct manipulation to the indirect manipulation of a graphics tablet. In addition, the pen's nib is rigid and its range of movement is only one or at most 2 mm.

On the other hand, the tip of an actual paint brush for watercolour or oil is flexible and it moves more dynamically. Some users want a touch sensation that is similar to an actual paint brush. They want to watch the tip of the brush bending, and feel the reaction and friction between the brush and the painting target while painting on the target.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.
*UIST'10,* October 3–6, 2010, New York, New York, USA.
Copyright 2010 ACM 978-1-4503-0271-5/10/10....$10.00.



Figure 1: Painting on a real dish with our system.

Therefore, we have moved digital painting closer to real-world painting. In other words, we developed a painting brush device and a painting system (Figure 1) that satisfies the following three requirements:

(1) It provides the sensation of an actual painting brush using tip bending and interactivity with a computer.

(2) Users can paint on both 2D and 3D objects.

(3) Users can paint on a real object surface while directly holding the object.

In this study, we developed the MR-based Artistic Interactive (MAI) Painting Brush to fulfil requirement 1, and proposed a painting model that produces a bending tip. In addition, we developed a mixed reality (MR) painting system for requirements 2 and 3.

**RELATED WORK**
There have been several simulations of traditional graphical styles with a graphics tablet [2-5] and the quality of such simulations is improving. However, in these studies, the users cannot see the brush tip while painting. Additionally, because the tactile feeling of the graphics tablet is different from that of a real painting brush, and because only the pressure and position of the nib can be measured, it is difficult to control the virtual brush in a similar manner as in the real world.

Therefore, we developed a device that imitates the shape and tactile feeling of a real paint brush. It can detect not only the position and orientation, but also the amount and direction of tip bending.

Ryokai introduced the I/O Brush [6] that uses a large brush-like device as a symbol of painting tool. This system uses a graphics tablet/screen hybrid to resolve an indirect manipulation problem However, bending of the brush tip is not considered. On the other hand, IntuPaint [7] and ThermoPainter [8] use physical or near-physical paint brushes, where the amount and direction of the tip bending are reflected in the painting results. However, in these systems, which use a back-projection technique, the users can paint only on the front of the screen.

In this research, we developed a mixed reality system with a see-through video head mounted display (HMD) to enable painting on various 2D and 3D physical objects.

The newly proposed MAI Painting Brush that we developed is a ToolDevice [9] for painting. The ToolDevice is a set of devices that employs a metaphor for existing tools that are familiar in everyday life. It is used for various operations, including spatial tasks, where the user selects the most suitable device from the set for the required manipulations. Various kinds of brushes, such as round brushes and flat brushes, are used for painting. In this study, we provide such multiple functions without losing intuitiveness, so that users can easily understand the usage of the tool from the device's appearance. In particular, we implemented a mechanism that switches the functions by changing brush tip attachments.

## MAI PAINTING BRUSH

### Footprint and stroke by paint brush

In this paper, we call a mark made by touching a brush to a painting target a 'footprint', and a line made by placing footprints continuously as a 'stroke' (Figure 2).

In interactive digital painting systems, it is important to determine the position and shape of a footprint in order to create a stroke. In previous work, some studies use a simple circle as the shape of a footprint [2, 6], and others use a virtual 3D model of a brush tip to create a footprint [3-5]. However, systems using a graphics tablet can detect only the position and amount of the pen pressure. Thus it is difficult to control the shape of a footprint with the same sensation as an actual paint brush. To generate various expressive brush strokes, the system needs to reflect actual brush-tip movements (i.e. the amount and direction of bending of the brush tip) in the shape of footprints.

A footprint could also change depending on the brush type. Most paint brushes fall into two categories: round and flat (Figure 3). A round brush is used for painting a strong or weak line, and a flat brush is used for painting large areas uniformly. In the real world, users choose brushes of various sizes and levels of softness, according to their artistic purpose. Therefore, the footprint should be changeable between these commonly used brush types.

### Implementation

After some analysis, we developed the MAI Painting Brush (Figure 4) which can perform the following two functions:

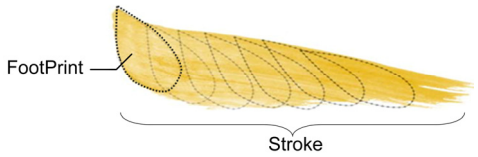



Figure 2: Footprint and stroke.

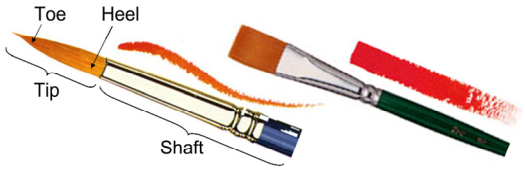



Figure 3: Actual paint brushes: round brush and flat brush

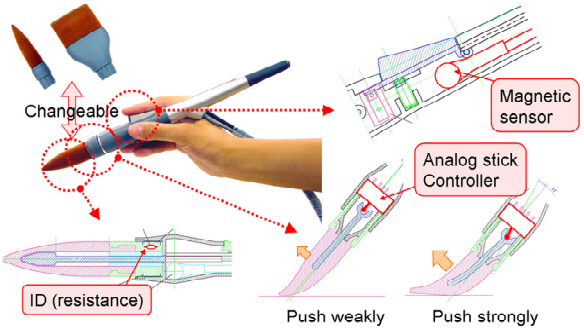



Figure 4: The MAI Painting Brush and its mechanism.

*Detection of the device position, and the amount and direction of tip bending.* We installed a magnetic sensor to detect the position and orientation of the device. We also installed a mechanism for detecting the brush tip behaviour to take advantage of directly painting real objects with a paint-brush-like device. Thus, we installed an analog stick controller in the shaft of the device to measure the amount and direction of bending of the brush tip.

*Detection of the brush shape:* Our device can be changed between the commonly used brush types by changing the brush tip attachments. We implemented round, flat and liner brushes. A liner brush is a round brush which can paint a line thinner than a standard round brush. The electrical resistance is in the tip of the device and the system can determine which tip is connected.

In this research, our device has a brush tip that imitates the shape of an actual paint brush.

## PAINTING MODEL

### Generating a footprint

*Basic shape of footprint.* In this study, the teardrop shape is assigned to a round and liner brush, and the rectangle shape is assigned to a flat brush/es (Figure 5), based on actual painting results by real paint brushes.

*Size and shape of footprint.* In reality, when the user presses the brush firmly, tip bending increases and the footprint becomes larger, depending on the size of the contact area. Moreover, when the user tilts the brush horizon-

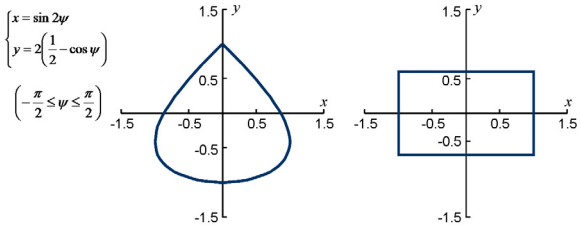



Figure 5: The basic shape of footprints in our system

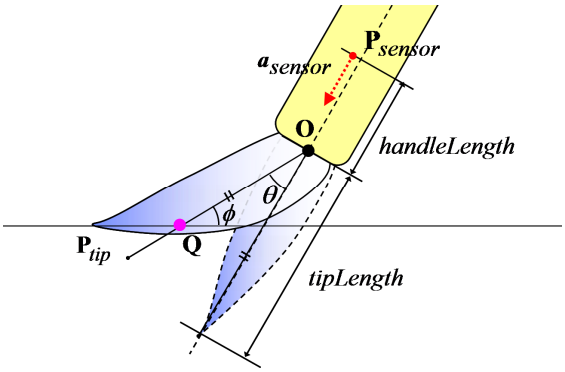



Figure 6: Parameters of the MAI Painting Brush.

tally to the painting target, the contact area also becomes larger. In this case, the width appears unchanged; however, the height appears stretched. Hence, the system stretches the width of the basic shape depending on the amount of bending $\theta$, and the height of that depending on the tilt, $\phi$, of the tip becomes more horizontal with respect to the painting target. Figure 6 shows the parameters of the MAI Painting Brush. $\theta$ is given by the tilt angle of the analog stick controller's stick from the default position, and $\phi$ is calculated by subtracting $\theta$ from the tilt angle of the device to the painting target measured with a magnetic sensor.

*Direction of footprint.* A real brush stroke is generated along the direction of the brush tip. Hence, the system rotates the scaled footprint in the direction of the brush tip.

Figure 7 shows the result of painting the footprint of a round brush using the abovementioned algorithm. The figures show that the footprint rotates and the size changes depending on the tilt of the device and the amount and direction of its tip bending.

### Calculate a painting point

To render a footprint, the system needs to calculate the painting point which is the centre of a footprint on the painting target. From Figure 6, painting point **Q** is a collision point of the line segment $\mathbf{OP}_{tip}$ that states brush tip and a polygon on the surface of the painting target. In this case, **O** is the heel and $\mathbf{P}_{tip}$ is the toe of the tip, which is considered to be the tip bending. $\mathbf{P}_{tip}$ can be calculated using the following equations:

$$\mathbf{P}_{tip} = \mathbf{R} \cdot (tipLength \cdot \mathbf{a}_{sensor}) + \mathbf{O} \quad (1.)$$

$$\mathbf{O} = (handleLength \cdot \mathbf{a}_{sensor}) + \mathbf{P}_{sensor} \quad (2.)$$

where **R** is the rotation matrix given by $\theta$, and *tipLength* is a measured length of the bent brush tip, handleLength is a measured length between $\mathbf{P}_{sensor}$ (the position of the magnetic sensor in the device) and **O**, and $\mathbf{a}_{sensor}$ is a unit vector that shows the orientation of the device. Finally, the collision point between $\mathbf{OP}_{tip}$ and the polygon is detected. This collision point, **Q,** is the painting point of a footprint.

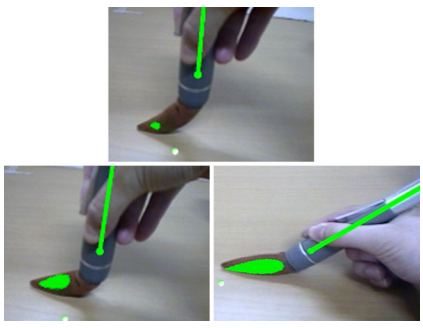
Figure 8 shows that a virtual line (which indicate $\mathbf{OP}_{tip}$) and spheres (which indicate **O**, **Q** and $\mathbf{P}_{tip}$) change depending on the amount and direction of the bending of the brush.

## MIXED REALITY PAINTING SYSTEM

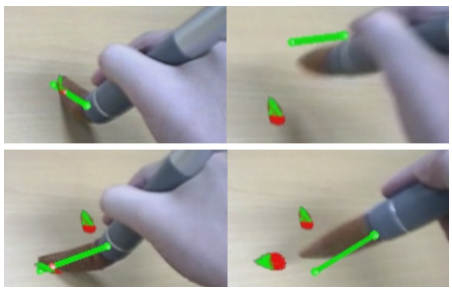
### System configuration

We developed a digital painting system called MAI Painting Expert. In this system, the MAI Painting Brush and its painting model were implemented. To produce this system, we used an MR system which has stereo vision.

Figure 9 shows the system configuration. Magnetic sensors are installed in a HMD and real objects are used to detect the position and orientation of the user's head and the objects in the MR space. Virtual painting on real objects is produced by superimposing the painting results on the 3D models which are mapped in the MR space on the position and orientation of the real objects. The 3D models are prepared beforehand.



(a) Changing the shape.



(b) Rotating.

Figure 7: Generating footprints.

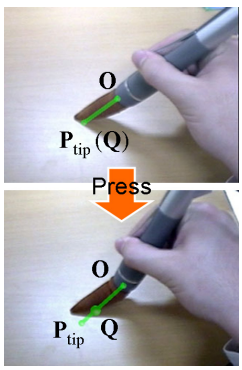



Figure 8: Moving Q, depending on the tip bending

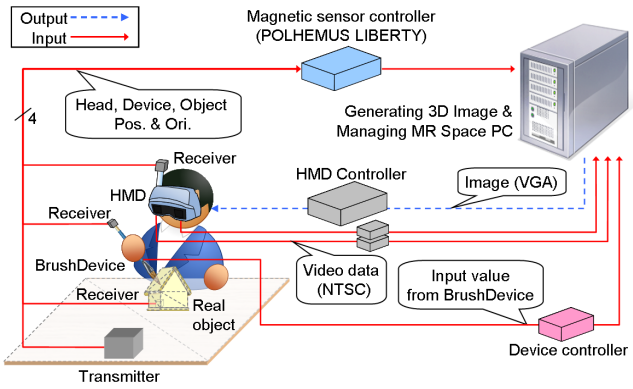



Figure 9: System configuration.

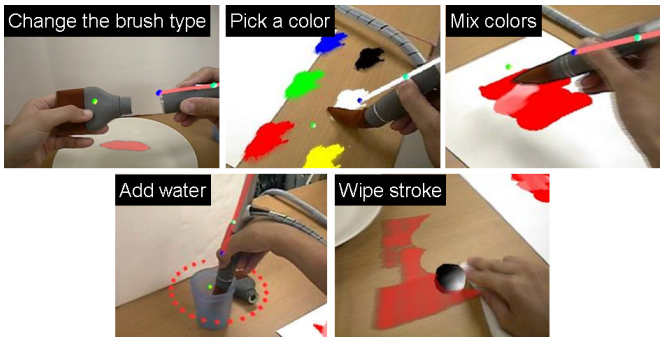



Figure 10: Painting operation in our system.



Figure 11: Painting examples

### Painting operation

Figure 10 shows the painting operation in our system.

(a) *Change/select the brush type:* The user can select from round, flat and liner brushes, depending on the purpose, and change the brush tip attachments.

(b) *Pick a colour and mix colours:* The user can select a colour from the colour palette and make new colours by mixing them.

(c) *Add water:* A real cup is on the table and the user can add water to the MAI Painting Brush to thin the paint. The user can re-mix the diluted paint on the palette.

(d) *Painting and erasing:* The user can achieve life-like painting effects, with the added bonus of being able to erase the brush strokes by wiping with a real cloth.

## USER STUDY

Our system has been experienced by a variety of people, including graphic designers, art college teachers, students who like painting, beginners at painting and so on. Figure 11 shows examples of the paintings done using our system.

After the experience, most users commented that they could grip the device easily, and the bending of the brush tip gave them a good tactile feel while painting. Many users held 3D physical objects and enjoyed watching and painting from various directions. They were surprised to paint on real objects in a similar manner to the actual painting, and some of them wanted to try painting on more objects around them. They painted by changing the attachments actively depending on their purpose, and the operation of changing attachments was evaluated as being quite easy and natural. In addition, since the users could paint a physical object with the physical device directly; some users recognized the tactile difference in the material of different painting targets, such as a wooden table, a ceramic plate and paper. This is a unique feature of our system, which a graphics tablet does not possess.

## CONCLUSION AND FUTURE WORK

In this research, we aimed to produce a painting system; MAI Painting Expert that imitates the painting of physical objects in the real world. To achieve this, we proposed a novel interaction device called MAI Painting Brush, which uses the characteristics of an actual painting brush, and a painting model using this device. In our system, because of MR, painting on virtual objects is also possible. Therefore, for future work, we plan to expand the device with a visual and tactile feedback mechanism that can represent the contact feeling of the device with a virtual painting target.

## REFERENCES


1. B. Gooch *et al.*: *Non-photorealistic Rendering*, A. K. Peters, Ltd., 2001.
2. C. J. Curtis *et al.*: "Computer-generated watercolor," Proc. SIGGRAPH 97, pp. 421 - 430, 1997.
3. N. S.-H. Chu *et al.*: "MoXi: Real-time ink dispersion in absorbent paper," Proc. SIGGRAPH 2005, pp. 504 - 511, 2005.
4. W. Baxter *et al.*: "IMPaSTo: A realistic, interactive model for paint," Proc. the 3rd Int. Symp. NPAR, pp. 45 - 148, 2004.
5. S. Saito *et al.*: "3D Physics-based brush model for painting," SIGGRAPH 99 Conf. Abstracts and Applications, p. 226, 1999.
6. K. Ryokai *et al.*: "I/O Brush: Drawing with everyday object as ink," Proc. CHI 2004, pp. 303 - 310, 2004.
7. P. Vandoren *et al.*: "IntuPaint: Bridging the gap between physical and digital painting," Proc. TABLETOP 2008, pp. 71 - 78, 2008.
8. D. Iwai *et al.*: "Heat sensation in image creation with thermal vision," Proc. ACE 2005, pp. 213 - 216, 2005.
9. A. Uesaka *et al.*: "TweezersDevice: A device facilitating pick and move manipulation in spatial works," Adjunct Proc. UIST 2008, pp. 55 - 56, 2008.