A Liquid Tangible Display for Mobile Colour Mixing

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ABSTRACT

Digital painting is an increasingly popular medium of expression for many artists, yet when compared to its traditional equivalents of physical brushes and viscous paint it lacks a dimension of tangibility. We conducted observations and interviews with physical and digital artists, which gave us a strong understanding of the types of interactions used to create both physical and digital art, and the important role tangibility plays within these experiences. From this, we developed a unique liquid-like tangible display for mobile, digital colour mixing. Using a chemical hydrogel that changes its viscosity depending on temperature, we are able to create some resemblances to the feeling of mixing paint with a finger. This paper documents the information gathered from working with artists, how this process informed the development of a mobile painting attachment, and an exploration of its capabilities. After returning with our prototype, we found that it provided artists with sensations of oil and acrylic paint mixing and also successfully mimicked how paints are laid out on a paint palette.

ACM Classification Keywords

H.5.2 User Interfaces: Haptic I/O; Input devices and strategies

Author Keywords

Artists; hydrogel; textures; digital painting.

INTRODUCTION

Digital painting tools have become a common form of expression for many artists, providing many capabilities that often surpass the limitations of their physical counterparts. Software such as Photoshop provides the digital artist with a complete art studio wherever they take their device, making digital creation very portable and accessible. Despite these enhancements, however, many key physical painting features are not emulated digitally. One such example is the lack of textural feedback that is provided when mixing different viscosities of paint – a key action that aids artists in achieving the correct dilution, and hence colour, of their medium.

Stemming from direct observations and interviews with both physical and digital artists, we saw an opportunity to develop a hybrid interface that combines the benefits of physical paint with a digital interface to provide the digital artist with a programmable, textured surface for colour mixing. This interface is designed to be used as an input palette that can be attached to an existing hand-held mobile device, giving the artist the ability to feel the texture of paint with their fingers on one side, whilst seeing the effect on the paint's colour on the other. Our novel interface uses hydrogel [8], a chemical substance that changes its stiffness based on temperature, allowing us to manipulate the apparent viscosity of the palette to give user feedback while mixing paint. We situate the chemical display on the back of the device to prevent obscuring the mobile's screen as the stiffness changes.

Figure 1. Left: Artist using palette and canvas. Right: Our digital prototype with tablet canvas application and mobile paint palette.

Our prototype includes both heating and cooling components to allow us to directly manipulate the viscosity of the gel palette based on user behaviour. While providing feedback in this form, the gel palette also acts as an input, detecting motion and altering the colour/dilution of the front display accordingly. Artists interact with the gel using their fingers—powerful sensory receptors—which enables them to mix digital colours with realistic texture sensations but without mess.

After presenting related work, we discuss a series of observations and interviews we undertook with both physical and digital artists. We describe how this informed our design and detail the implementation and capabilities of our prototype. We finally discuss the artists' feedback on the prototype before presenting opportunities for future work.

RELATED WORK

There is a large body of work that explores enhancing interactions with digital painting interfaces. The CavePainting project presents an interface to create 3D works of art in a virtual reality cave environment [5]. It uses physical props and gestures for an intuitive interface for artists. Other painting interfaces have explored novel stylus technologies to offer finer, more realistic controls [16, 15, 9, 13]. Another related project is FlexStroke, which is an example of a deformable stylus [7]. Its dynamic stiffness ability affords the feeling of different types of brushes. A further novel painting interface is EMS

Figure 2. Painting Tools. Left: Artist knives. Centre left: Artist pens with interchangeable nib sizes. Centre right: Brushes – these three different brushes were being used simultaneously by an artist. Right: Artist using painting knives for raised areas.

Painter [2]. This enables an audience to influence a painter bush strokes through electrical muscle stimulation.

Other novel stylus designs such as the I/O brush enable drawing with everyday objects as ink [11]. Similar work demonstrates using everyday physical objects as a paintbrush [6]. A related implementation is Mix brush [10], which uses an innovative colour mixing interaction consisting of a stylus with RGB LEDs wired through its centre. The LEDs light up for each colour the user selects. We also see an example of tangible painting in an exhibit for a museum [1]. This provided children with a TUI for interaction with paint pots. A similar tangible emulation is MobiSpary [12]. This is a mobile gesture-based control app that provides a natural pointing mechanism for a virtual spray can. Similar to our work, previous studies have taken a user-centred design approach with artists. Jalal et al. explored how artists and designers interact with colour [4], using these insights to develop novel GUI based colour tools. Other studies have worked directly with illustrators [14]. The large majority of previous work in bringing tangible elements to digital painting has focused on innovative stylus technology for realistic painting tools and brush effects. While some work has investigated colour mixing [10, 11], we are yet to see explorations into texture interactions for digital painting.

There have been many technical approaches to dynamic textures for broader applications. Harrison et al. provided dynamic physical buttons on a visual display [3]. Another approach uses microfluidics, as seen in Tactus [18] We also see manipulated pneumatics for tactile response related to levels of force input [17]. The work of Miruchna et al. introduces temperature-actuated hydrogels [8]. They demonstrate adding this to a mobile resistive touchscreen to support tactile feedback. We apply this type of interaction to our prototype. Our goal here is to use hydrogel's soft states to resemble the feeling of paint, and its actuation capabilities to allow dynamic placement of interface elements.

OBSERVING ARTISTS

At the start of this project, we wanted to discover elements of traditional painting that would inspire the development of textures and materials for new tangible interfaces for digital art. To achieve this we a local art group session to observe how people work. Within the group, artists were teaching each other and planning exhibits to sell and showcase their work. We observed and interviewed seven artists at the class, two whose focus was sketching and five who focused on painting. The members ages ranged from 46–72, and all had been practising their art for over 10 years. During the art session, we observed and recorded how members created their art, and asked questions about their processes. Information was collected via note taking and photography.

Artists' Tools

First, we discussed brushes. While painting, artists would use different types of brushes simultaneously (see Fig. 2). This was to take advantage of the different properties available in each brush. One painter explained that it was not only the size of a brush that was important but its stiffness, too, as this allows the artist to bend the bristles on the canvas for different spreads of paint. One of the artists also manipulated her brushes further. She cut an old worn out brush to create a realistic fur effect in an animal painting. We also saw duplicates of identical brushes only with different colours, with artists holding the other brushes between their fingers to keep different colours ready-to-hand.

The artists also work with unique tools to create different painting effects. They explained how they manipulate the bristles of a toothbrush via squeezing and flicking to transfer the paint onto canvas. Knives were also a commonly used tool (see Fig. 2), used to spread and create raised areas on the palette and canvas. For example, one artist was painting blossoms using this effect (see Fig. 2).

The sketchers occasionally used black washes and watercolour pencils. These colours would be applied via the pencil, and then water was added to blend the colours. As with many artists, they sketch when out walking, and try to quickly capture on the move, leaving notes for what they miss so they can draw and colour later.

Paint Mixing

The painters used watercolours, oils and acrylic paints. Water paints are very thin with a runny consistency. The artist we observed using them would first wet their bush, then rub this against the block of paint until the water took on the colour. They then dragged this coloured water to their palette, and from there took the colour to their painting. When they mixed multiple colours they would first do this for each colour, then begin dragging from each watercolour source to make their

Figure 3. Examples of physical paint mixing, showing the trails often created as artists select and combine colours in varying intensities.

new colour. If they needed the colour to be brighter they would add more water to it. If they needed the colour to be darker they would add more paint.

Oil paints are described by the artists as a lot thicker to work with, and are naturally darker in colour. The artists would squeeze out a selection of colours onto their palette from the paint tubes. Then then dragged and mixed the paint to different sections of the palette, taking a bit of paint from each of the blobs that had been squeezed out. They add white paint or a lighter version of the colour to make the colour brighter, and black or a darker colour to darken. When working with oils one of the artists explained how they scoop large amounts on to the canvas as it is absorbed quickly.

The artists described that using acrylic paints felt like a mix of the two other paint types. The process of mixing resembled the oils, but the textures of the paints were more water-like.

All the artists mixed their paints on to palettes before applying to canvas (see Figs. 1 & 3). Each of the painters said they mix colour by trial and error. They start with a knowledge of what colours are needed to make a starting colour, adding these to their palette to begin. They then go through stages of adding a bit of each part to different areas of the palette. Colours in various mixed stages are spread across the palette, maintaining the different shades (see Fig. 3). As part of this process, the artists tend to put the different colours of paint in specific locations to help easily recall where they are.

Digital Art

Alongside the art group, we worked with an artist (Male, 44) who practises both digital and traditional painting techniques. This aided our understanding of how traditional techniques are emulated in digital art applications, and how this changes the paint mixing workflow. In an interview, we discussed the tools available to digital artists, the benefits of digital techniques, what tangibility he misses, and his workflow for selecting and mixing colours. He opened the discussion explaining what he found to be the major benefits to digital painting. First was the eraser, and he demonstrated in a painting app how it helps him achieve sharp edges. The other benefit he pointed out was manipulating the canvas. He explained how it is very important to create distance between you and your painting, and a digital app makes it easier for you to infinitely zoom out.

When we asked about his workflow for colour mixing, the artist explained that he picks his colour values according to a scale (e.g., 0–10 for shades of a single colour). He lays these colours out onto a palette and adds or removes white to go up or down across his scale. He imitates this process in digital by instead of a physical palette, using hidden layer in Photoshop. He uses the pipette tool to pick and place active colours. He uses blend tool or smudge tool to mix digital colours. This is done by layering dark to light and then blurring the edges. He commented how "It looks great, but you're not getting that feeling of mixing". He also noted that other artists may build up layers using the opacity tool, though he has never tried this.

The artist was very clear digital lacked tactile feel. No matter what tools he tries, everything feels like a screen. Contextualising this, he spoke of the drag factor on his physical palette and sketchbooks, and how everything normally has a different feel to paint and draw on (e.g., from canvas to tonal paper to cardboard, etc) – he said that he prefers the drag. Turning to other benefits of tangibility, he said "with digital work, I love it when it's on the screen, but I don't feel as if it is finished until I have a hard copy," and how this was especially important when working with a client as he felt it relates to their value for money. We also discussed the possibility of mobile digital art. He personally does not regularly use a mobile device for art due to limitations such as screen glare, battery life and screen heat. Despite this, he pointed out that a tablet would weigh less overall than physical tools by the time you have packed, say, a pencil case and sketchpad.

Discussion

A large take-away from our study was the role of physical gestures for mixing colours. The way artists interact with their physical palettes is very different to modern painting applications. There is a loss of physical gestures and textures of mixing paint on the palette before it is taken to the canvas. Key physical gestures such as dragging, scooping and stirring play a large part in physical colour section. This is absent from the digital experience. We saw how physical dragging of the colours around the palette allows maintaining a range of different shades. It also gives artists spatial knowledge of where their different colours are located. This allows the artist to maintain flow in their work. The amount of paint scooped determines the amount the artist brings over on the brush or knife. Then the amount of physical stirring gives fine control over how paints are mixed. We saw the palettes had a certain order where colours have organically developed, and their evolution through the many shades created forms a trail across the palettes. This gave a sense of physical history to the colour section process.

PROTOTYPE DESIGN AND DEVELOPMENT

Based on observations reported, we began ideation around a scenario of physical-digital painting. This concept would provide the many benefits of digital painting without losing the physical sensations experienced when painting physically. It aims to offer a seamless interaction between physical materials and digital information. After seeing the important role the physicality of paint played in the artists' creative process, and indeed the joy it instills, we wanted screens to be able

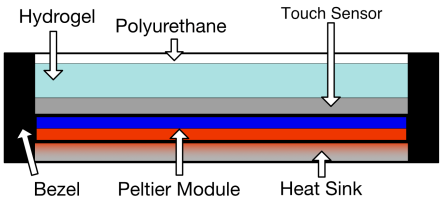

Figure 4. This figure illustrates the layers of the prototype used to activate the gel. Here a Peltier module is set to cool the gel (blue side).

to transform into paint-like material, as this physical feel of paint is absent from today's digital painting tools. To begin to understand how such a design could be introduced, we imagined a scenario where areas of a screen could have varying viscosity representing different paints. This would allow users to dip, push and swirl around areas of the screen like a painter's palette. To aid in the realisation of this, we undertook designing and developing an early prototype that shows materials that could offer the beginning of a physical-digital painting experience. The prototype aimed to deliver: textured paint mixing sensations; support for stirring paint using the textured material; and, separation of palette and canvas in a mobile system pairing mobile phone and tablet devices.

To achieve these goals we explored the use of adding contained hydrogel to the back of a mobile smartphone, with the goal of providing tangible colour mixing that fits in the palm of the artist's hand. This layer of viscous material can be used for haptic colour mixing, simulating the physical sensations of paint. Hydrogel can actuate from stiff to soft, providing artists with a tangible sensation of thinning paint for different shades of colour. The output of the colours are seen on the phone application. From here the artist can pick the colour and paint on their canvas. We provided a canvas application on an iPad, which then paired with the tangible palette phone for transferring colours.

Hydrogel Paint

As one of our key goals is to simulate the sensation of paint, we needed to find a material near to the viscosity of paint that can be manipulated by both the computer and user. We experimented with hydrogel, a soft and viscous chemical with similar properties to those of paints. It also has the ability to stiffen when heated. This means we can actuate the material via stimuli triggered by a computer. This offers us different levels of stiffness to simulate different kinds of paint depending on the user's desired interaction. The actuation works by first heating the gel to a stiff state. When cooled, the gel softens. This variability can then be mapped to the stirring and thinning out of paint. We also saw this variability as an opportunity to simulate different types of paints such as oils, acrylic and water paints.

After testing the hydrogel had potential to simulate paints within a lab setting, we began the technical challenge of changing the temperature on-demand paired with a graphical output. In our initial test we used a resistance wire that ran through the gel and was heated using a power supply. While this worked well in heating the gel, we needed a process for cooling the gel as quickly as we were heating it, to provide the most natural

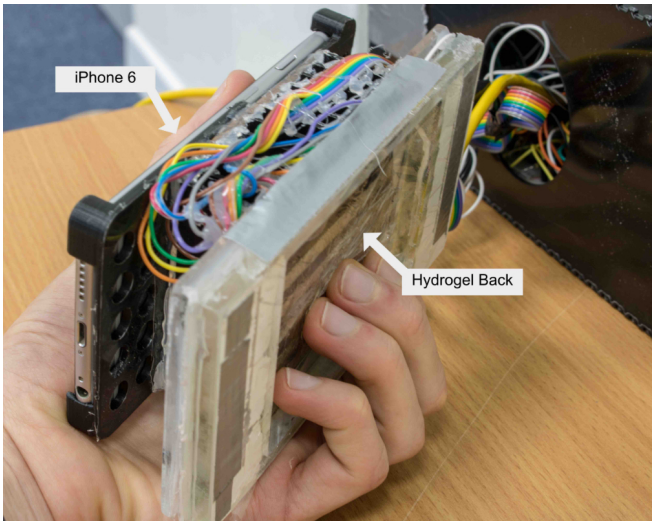

Figure 5. The handheld mobile prototype, showing the hydrogel case accessory and the phone it is used to interact with.

interaction for the artists. We also needed this process to be reversible, so whatever the gel was placed on needed not only to heat but also cool the gel. We accomplished this by using a Peltier module. These solid-state heat pumps produce thermoelectric heating and cooling when current flows through them. During the process, one of the sides will heat up while the other will cool down. If the current flow is reversed, the opposite sides will heat and cool. This means we can switch the temperature programmatically, making the stiff to soft actuation programmable in an interactive system. We also added a heat sink to the side of the Peltier opposite the gel, aiding cooling and speeding up the process of state switching.

Combining with a Mobile Phone

In order to provide interaction with paint, the system needs to detect the location and pressure of the user's interactions with the gel. We achieved this by placing the gel on a touch-sensitive layer of Velostat with a grid of conductive tracks that allowed us to detect touches at intersecting points. This is also capable of sensing the force of the user's touch, which allows for mapping of how quickly the gel should soften.

Having provided both sensing and actuation, we then needed a way to display the colours the users will be mixing. One limitation of hydrogel that it becomes opaque when stiffened, obstructing whatever is behind. This limited the possibility of putting the gel over the screen, as colours would only be visible when the gel is in its softest state. This prompted us to put the graphical output on the front of the device, and the hydrogel on the back. Doing this supported the interaction of holding the mobile in the non-dominant hand to mix colours while using the other hand for painting, resulting in a palette and easel set up as seen in our artist observations.

We constructed the system to work with an iPhone 6. The final attachment is made up of the touch sensor, gel, Peltier modules and heatsink, and also contained an area for the phone to clip in and out of. The phone connects to the attachment via Bluetooth. This communicates the touch location and the

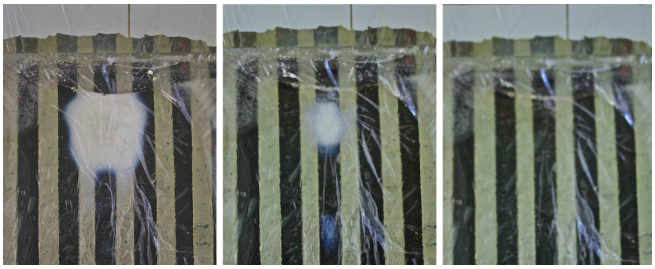

Figure 6. Hydrogel states as temperature is changed, Left: The gel is at its hardest, feeling like an oil-based paint. Centre: The gel is softer and thinned out, feeling more like an acrylic-based paint. Right: The gel is now at its softest after being fully thinned out, and feels more like a water-based paint.

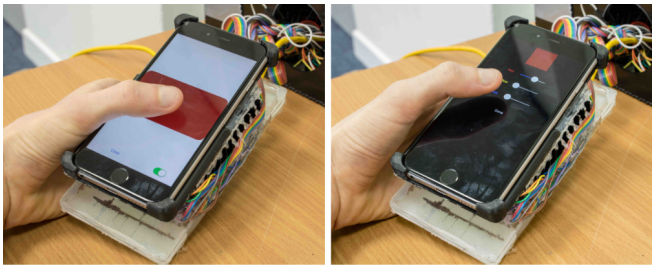

Figure 7. The GUI displayed on the phone. On the left is the menu to select the initial colour. On the right we see the chosen colour now in the centre pot, which activates the gel in that area on the back of the device.

state the gel is in. The paired phone application processes the input, and the paints are displayed in the correct location with the appropriate saturation. To interact with paints, the user selects a starting colour in the app. The app currently provides three on-screen paint areas to start a colour mixing interaction. The user can tap each area and place a starting colour. The colours are selected using red, yellow and blue colour channels, manipulated with a slider for each one. Once the colour is selected they can manipulate its saturation using the gel on the back. All colours can be reset using a button at the bottom of the screen.

Final Interaction

At this stage the user can hold the device in a single hand with their fingers on the back to reach the gel, while their thumb on the front screen is able to select the desired starting colour (see Fig. 5). It also moves us toward envisioning the gel palette in the form of a mobile accessory that can be added to any standard mobile device.

The user begins their interaction by picking the colour on the accompanying phone app (see Fig. 7). This imitates how an artist would pick out their starting paints to place on the palette. Once the colour is set, the gel on the back of the phone can be manipulated, as touch sensing and temperature control in that area is now active. When the user touches the back of the mirrored location of the paint on the screen, the touch is registered as an interaction. From this point, the user can push and rub the gel. This will cause the gel to be actuated toward a softer state. These stages of actuation are illustrated in Fig. 6. Simultaneous to this, the user will see the colour on the phone screen decrease in saturation. This interaction process simulates thinning of paints to alter shade. Once the user has mixed their desired saturation they can select it with their finger or stylus on the phone screen. Then then use the colour on the canvas application (see right of Fig. 1).

FEEDBACK FROM ARTISTS

We returned to the art class where we originally studied traditional painting techniques in order to demonstrate the prototype and give the artists an opportunity to use it. The feedback session took place over the course of two art classes with five artists, during the session's tea/coffee break. The artists' age ranged from 46-72 and all had been practising their art for over 10 years. We demonstrated the system's functionality and outlined its goals. The artists then used the system individually, and we showed them how to pick a colour and feel the back of the screen to mix it. We asked them to talk aloud about how it felt, and how it compared to real paint. During this time we observed and recorded what they did. After this we spoke to the whole group together to gather further feedback, taking notes throughout. These sessions allowed us to gather feedback about how the prototype compares to traditional painting. Specifically, we wanted to find out if the material felt like paint to people familiar with paint's consistency. We also wanted to understand how the gestures mapped to their analogue counterparts. Finally, we asked if the artists had any suggestions for improvements or future features that would be of benefit to them or other artists.

Results

Each of the individuals that used the system was impressed that the gel felt like certain types of paint. Some particularly liked how the initial 'blob' of paint they lay on their real palette was like how our system starts with the gel in the thick state. They explained how its behaviour is similar to flattening and spreading out the paint blob to mix their colours. As a group, they agreed the hydrogel was similar to the oils and acrylics, but water paint was not as similar. They explained that the gel was still too viscous, and they could notice that it was different from water paint even when it was fully cooled to its softest state. One participant explained that the softest state was more like a watered down version of acrylic paint.

For two of the artists, we observed that the thick blob that appears at the start of the interaction helped them detect where their finger needed to be to mix the paint. The rest of the group would simply glance at the back once to position their finger. One of the artists' main feedback points was about the use of knives with paints, explaining that this was her preferred method of painting. She suggested how adding this use-case to the gel would appeal to her. This prompted another artist to suggest brushes too. This feedback gives direction to consider how tools could be used with the gel in future work.

Another area of feedback was about the device's limited output. The artists explained how the back felt real and interactive, but what was seen on the front was still only a flat digital colour. One artist asked if it would be possible to scoop up the gel to spread on the canvas, as tapping the colour after mixing is not as exciting as scooping real paint.

Overall, the traditional artists gave us valuable feedback. We learnt how our device did have close resemblances to oil and acrylic paint, but was still lacking the sensation of the softest of water paints. We also saw how the hard blobs of hydrogel on the back of the prototype simulated another element of the physical painting experience, and how it helped some artists find the intersection points to interact with. Finally, despite the artists not wanting to adopt digital art into their main workflow, they enjoyed using the system and thought it had value in effectively imitating oil and acrylic paints.

DISCUSSION AND FUTURE WORK

This use of programmable liquid tangible controls has great potential for bringing more engaging forms of interaction with digital art. Our prototype has shown early potential with existing hardware and accessible chemistry. Our future aim for the prototype is to deploy it with artists over a longer period of time. This will allow us to gather expert insights as to whether the device is valuable for this context. Alongside this we also wish to improve interactions with the gel. We saw the key role different tools had during our observations, but currently the gel only works with the user's fingers. The inclusion of tools such as brushes and knives holds potential for our eventual vision.

Hydrogel, so far, has worked well in achieving our goal of tangible sensations of paint for digital painting experiences. During the development and evaluation of the prototype, we encountered several limitations of using the gel for mobile art-based technology, however. While we were able to create paint sensations for the artists, development of a mobile hydrogel palette for everyday use may raise a range of physical and technical challenges. For example, the temperature of the area in which the gel is stored impacts its longevity. Keeping the gel in conditions at room temperature and above can cause it to dry out. In this case the gel would harden, but would not be reusable when cooled. This evidently imposes limits on the situations in which such an approach can be used, perhaps even completely excluding users in extreme climates.

In order to maintain the gel's functionality, it needs to be kept fresh and uncontaminated. We achieved this by encasing the gel in a clear plastic film. While this removes the issue of contamination, the film limits the interaction the user can have with the gel when compared to real paint. Users can not, as one artist requested, scoop the gel out to place elsewhere. Currently, our prototype is limited to dragging, pressing and rubbing on the activated surface. Scooping and placing the gel would be a further challenge in making our system closer to the traditional paint experience.

The gel was not able to effectively simulate water paint for the artists. This is a limitation of the gel itself, as it needs to be of a stiff enough base consistency to simulate oil and acrylic paints. To make the gel more water-like will require the addition of more liquid. This will make the actuation slower (or cause it to fail to stiffen), affecting the user's experience with the oil and acrylic simulations. It will also require more heat, which is something the system currently cannot provide.

The final limitation of the prototype is its opacity. Artists were originally confused about why the gel was on the back of the screen and the colours were on the front. We see this interaction as a way to provide an additional tool that users can hold in their non-dominant hand and interact with as they hold it naturally. However, being able to colour the gel itself and transport it from palette to canvas might provide a more seamless interaction.

CONCLUSION

In this paper we have outlined insights into the role of tangibility in traditional painting and its relation to digital applications based on observations and interviews with experienced artists. Based on these insights we introduce a potential method for providing tangible texture manipulations and simulating paint mixing. We developed a prototype that begins to facilitate this tangible interaction for paint mixing. After gathering feedback on this prototype we saw that it demonstrates the potential for providing programmable liquid tangibility of oil and acrylic paint mixing. Future work will explore ways to further integrate its tangibility into artists' workflows.

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