Deformable Paint Palette: Actuated Force Controls for Digital Painting

Cameron Steer
FIT Lab, Swansea University,
Swansea, UK
705784@swansea.ac.uk

Jennifer Pearson
FIT Lab, Swansea University,
Swansea, UK
j.pearson@swansea.ac.uk

Simon Robinson
FIT Lab, Swansea University,
Swansea, UK
s.n.w.robinson@swansea.ac.uk

Matt Jones
FIT Lab, Swansea University,
Swansea, UK
matt.jones@swansea.ac.uk

CHI '17 Extended Abstracts,, May 6–11, 2017, Denver, CO, USA.
ACM 978-1-4503-4656-6/17/05.
http://doi.org/10.1145/3027063.3053219

Abstract
This work-in-progress presents early findings on using deformable interfaces with force input to enhance interactions with digital painting applications. Our prototype uses deformation to *submerge* controls to represent paint pots, and *emerge* controls to represent nibs. These controls can then be pressed or squeezed to change the colour or size used for painting. Our preliminary study evaluates the prototype against a tablet. Early findings show participants were quicker and more accurate using the tablet, and found mapping of their input force to response unclear when using the prototype. Despite this, participants enjoyed using the deformable interface, stating that tangibility was useful for the use experience. We report these results and offer suggestions for improvement of the deformable interface.

Author Keywords
Deformable devices; tangibility; shape-changing; force input; digital painting.

ACM Classification Keywords
H.5.2 [User Interfaces]: Haptic I/O; Input devices and strategies

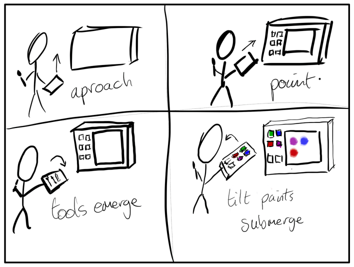

Figure 1: A scenario for deformable painting tools. The user approaches the canvas screen with the deformable (top left). The canvas activates (top right). When the user needs to select a brush and size, sensels emerge (bottom left). Then, the user needs to select a colour and saturation, so the sensels submerge into paint pots (bottom right).

Introduction

Making physical objects requires diverse tools – from the sets of brushes required by artists to bring paintings to life, to the knives used by chefs to achieve the correct cut with food. Digital creation offers a similarly diverse toolset, but it is not limited by boundaries such as weight and space. Software such as Photoshop provides the digital artist with a complete art studio wherever they take their device, making digital creation more portable and accessible. Yet with these advantages comes a potential loss of physical engagement. Tools in GUIs offer little tangible diversity, feeling the same even if their function changes [19]. Deformable interfaces introduce the concept of dynamic tangible controls which combine the benefits of physical objects with the portability and accessibility of digital controls.

Imagine a flat, portable device that can actuate to provided submerged paint pots which can then be pressed to change and mix colours; and, emerge to provide graspable nibs that change size when squeezed (see Fig. 1). These different elements change and deform as the artist requires them. The benefits we aim to deliver are: eyes free control to minimise distraction; and, bringing elements of realistic painting to digital experiences. To fulfil these aims, our current work has explored the use of force input that facilitates variable squeezing and pushing gestures. In our deformable prototype, actuation provides submerging to form paint pots and emerging to form nib controls. In this work, we compared the deformable prototype to sliders on a touch screen, recording the speed of selections and accuracy of matches. We discuss here the results of this study and early feedback gathered from participants.

Related Work

Shape-changing interfaces have been explored in a wide range of studies [12, 13, 16]. Work such as Haptic Chameleon [9] proposes controls with dynamic shape change. There are also flexible input control interfaces such as MudPad [5] and Force Form [18] where users can push into the interface. However, so far these interfaces have not provided users with analogue input. Other forms of shape changing displays deform grids of sensels [2, 8, 11, 20], combining screen deformation and dynamic tangible controls. The work of Robinson et al. [14] highlights the benefit for eyes-free control over touch-screens. Researchers have also explored tangibility in digital painting. For example, using virtual reality [6] or dual touch-screens with tactile sensations [4]. Other examples use tangible painting in exhibits [1]. Research has also been conducted on force detection (e.g., [10]) including exploring the use of force on touch-screens [3, 7, 17].

We see many examples of shape changing displays that transform to present dynamic controls. Currently, however, no dynamic controls have the ability to sense force interaction. With current force-based controls, none yet offer actuation to present different forms of controls. We also see examples of tangible painting controls, none of which have the ability to deform or offer force-based interactions. This uniquely positions our work in a space that combines these three areas. This work expands the interaction possibilities by: providing a prototype that dynamically switches modes of control; providing force control as a new input for shape-changing interfaces; and, situating these elements in a digital painting scenario.

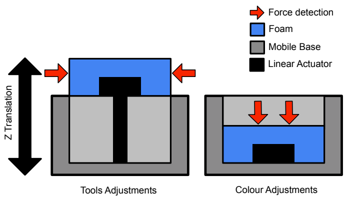

Figure 2: This diagram illustrates the different states the sensels support, along with the force sensing directions used. When the sensel emerges (left) it forms the nib for nib resizing. Here the force upon the sides of the foam forms the squeeze gesture. When the sensel submerges (right) it forms a paint pot for paint selection. Here the force down on to the foam forms the push gesture.

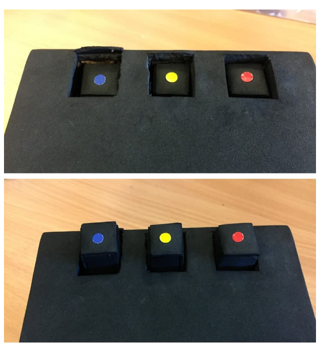

Figure 3: The deformable prototype, showing its push controls (top) and squeeze controls (bottom).

Prototype

We prototyped a deformable interface with an accompanying painting application that allows users to select colour saturation and nib sizes. When the controls sink into the screen they form primary colour paint pots, which users can press to alter the colour saturation. Pressing harder makes the colour brighter. To mix colours, users simultaneously push down on two or more paint pots. When the controls emerge from the screen (see Fig. 2) they form nibs that can be squeezed to change the nib size, with the three controls mapping to either a pen, pencil and brush. The harder you squeeze, the smaller the nib.

The prototype consists of three actuated sensels [15] (see Fig. 2) controlled using a string, pulley and stepper motor. This string pulls the sensel down as the stepper motor rotates. Each sensel has five force sensors on each square foam-encased face. The foam provides texture when manipulating the sensels and gives a sense of shape manipulation when squeezed and pushed. There is a sensor on the top surface to detect push interaction during submersion, and a further four on the side surfaces to detect squeezing during emersion. We made the sensels square for effective force sensor positioning and to allow them to lie on a flat surface for optimal force detection. When the deformable connects to the painting application we perform a calibration providing consistency across interactions. Finally, we added a coloured marker to each sensel to minimise cognitive load on the user.

User Study

To gather early feedback, we conducted a lab-based study with 16 participants (7M, 9F, aged 21–53). Our aim was to compare our deformable prototype to a GUI control system, and gather subjective comments. Studies took, on average, 50 minutes each.

To compare our prototype to colour and nib controls seen in digital painting apps, we created a tablet control system (GUI) which uses sliders in place of the pressing and squeezing controls in our deformable (see Fig. 4). The moveable part of the sliders on our control interface were the same size as the deformable sensels, and in the same physical location.

The setup of the study involves participants using our interfaces as controllers for altering the colour saturation and nib size of a cursor in a custom painting application. This application is displayed on a single touch-screen canvas in front of the user (see Fig. 5). Participants then use either the deformable or the GUI to select a nib and paint colour, then directly paint onto the canvas using their finger.

Tasks and Procedure

The tasks in each study were split into two parts. The first was a set of closed tasks which directly compared our prototype to the GUI in terms of the speed and accuracy of selecting paint colour and nib size. This was followed by a more freeform task that allowed participants to explore the features of the controllers in a less restrictive manner.

In the closed tasks, participants were required to use the interfaces to match colours (via the pressing of the submerged paint pots) and nibs (via the squeezing of emerged nibs) on-screen. The same task took place on the GUI using the sliders to control each variable. In each case, the canvas would display the required colour or nib size, and the participant would try to match it using the interfaces as controllers.

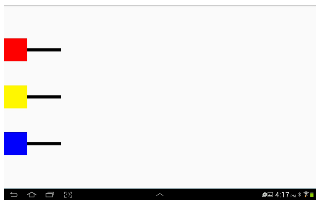

Figure 4: The interface participants used on the touch screen, made up of three sliders for colour choices, and appearing the same size as the sensels on the deformable prototype.

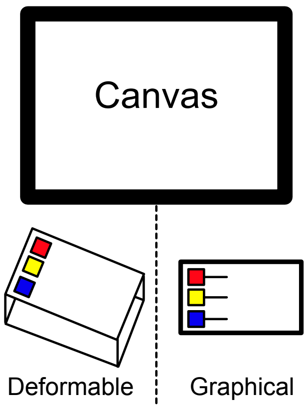

Figure 5: Study setup diagram. Top: the canvas that displays the painting app. Bottom: controls used for paint and nib selection.

Once they perceived that they had matched the colour on the canvas, the participant pressed 'next' on the canvas to move on to the next task.

Participants were required to make six sets of six matches per interface (each set has a mix of colours and nibs presented using a Latin square design) and were asked to complete the tasks as quickly and as accurately as possible (there was no time limit). After each using each interface, they filled out a Likert-like questionnaire giving scores out of 7 (1 low, 7 high) for visual attention, perceived accuracy, ease of use, perceived speed and enjoyment.

After completion of the closed tasks, participants were asked to use each controller to copy a simple image of flowers. This image had a mixture of colours (including ones that could only be made via the mixing of paint pots) and nib types and sizes to encourage participants to explore all functionality of the prototype. We gave very little instruction in this task; our goal here was to allow participants the freedom to use the deformable in a more naturalistic way.

Each study began with demographics questionnaire, followed by the open and closed tasks, and concluded with an interview about their experiences.

Results

A t-test was used to determine the effect the interface had on ability to match paints ($t(287) = 3.561, P < 0.001$) and nib sizes ($t(287) = 9.230, P < 0.001$). In both cases the GUI was more accurate, with an average difference of 4.2 % for paint selection and 45.7 % for matching nib sizes (see Table 3). Time results also showed the interface had a significant effect on how long it took to make match nibs ($t(15) = 6.845, P < 0.001$) and match paints ($t(15) = 3.412, P < 0.05$), with the GUI being significantly quicker. We saw a 3.9 s difference between matching nibs and a 2.9 s difference between matching paints (see Table 4).

Question	GUI	Deformable	Z	P
Visual attention	5.5	5.0	1.94	0.052
Perceived accuracy	3.5	5.0	2.32	0.021*
Ease of use	6.0	5.0	2.67	0.008*
Perceived speed	5.0	4.0	1.92	0.055
Enjoyment	5.5	5.0	2.67	0.635

Table 1: Median Likert ratings (1 low, 7 high) from matching task. Significant results marked with * (Wilcoxon).

Question	GUI	Deformable	Z	P
Matching Colours	6.0	5.5	0.111	0.912
Matching Nib	5.0	4.0	1.594	0.111
Visual Attention	5.5	4.5	1.268	0.205
Enjoyment	5.0	5.0	1.592	0.111

Table 2: Median Likert ratings (7 high) from the freeform painting task. Significant results marked with * (Wilcoxon).

Table 1 shows significant differences between perceived accuracy and ease of use for the matching tasks. The freeform painting tasks yielded no significant differences in any of the questionnaires (Table 2).

In the post-study interview, five participants said the deformable allowed them to dedicate more focus to the task. One stated: *"I don't need to see the interface, I can just put my finger on it"*, and another said: *"I was looking more at the screen for the deformable one"*. Contrary to this, one participant said: *"I didn't have to look when I had the slider, but with the square thing [deformable] I kept looking down"*.

	Deformable	GUI
Both	37.02%	11.93%
Nib	60.39 %	14.36%
Paint	13.66%	9.58%

Table 3: Average error ratings for the two systems (%).

	Deformable	GUI
Both	17.80	15.87
Nib	13.55	9.68
Paint	12.16	9.17

Table 4: Average time taken to complete tasks using the two systems (seconds).

Seven people preferred to use the tablet for both selection types, while two preferred the deformable for both. The remaining seven were mixed across the two selections types. Within this group, four preferred the deformable for nib selections, stating, for example: *"[It] just seemed to work better, seemed easier to understand"*, or: *"you could see that instant response between the pressure of your hand and the size of the nib [...] I was just thinking I want that smaller and I was squeezing at the same time whereas in the slider one it just seemed more clunky"*. The remaining three participants preferred the deformable for colour selections, blaming issues with the tablet: *"sometimes I [would] miss it [sliders] and I couldn't get it right"*. Each of this group favoured the tablet for the nib selection. When asked which system they enjoyed using most, eleven chose the deformable because of the novelty and tangibility.

Another theme—as mentioned by six participants—was judging how much pressure was required. Four of this six explained this to be a reason why they preferred the GUI, as the sliders visually displayed their state (e.g., *"on the touch screen you can see what you're doing; with the sliders you can see the extent you're supposed to go. With the deformable one I just had no idea where to start"*). These four agreed this meant they looked down more with the GUI.

When asked about future uses, one theme was creative apps. Participants said: *"I can imagine doing creative work with my sons"*, *"drawing, maybe computer aided design"*, and: *"I might use it for art stuff as I actually think despite the fact I found it easy on the touch screen my deformable picture was closer to the original one [...] normal artistic stuff is done by hand [and] the fact it's done by hand maybe has a tactile advantage"*. Another theme was scenarios that needed remote control (e.g., *"definitely controlling devices when you use other stuff. So you don't have to focus on the tablet like when you drive and change the radio"* or *"controls like volume, TVs, white goods maybe"*). This theme is interesting as remote control objects require eyes-free attention – a benefit offered by tangibility.

Discussion

In this study, we saw that the tablet was more accurate and quicker to make selections than the deformable prototype. Despite this, participants enjoyed using our prototype which suggests promise for deformables providing tangible controls for digital painting.

Participants found the nib selection difficult, which resulted in a lower accuracy. However, participants still voiced that they liked using the squeeze action. Those who did not favour this control explained their issues with sensitivity – a possible limitation of the early stage hardware. Paint selection held more promise for future development, taking into account the feedback and limitations we observed. In the interviews, participants stated the difficulty in judging how how much pressure was required. The low accuracy may have been due to the difficulty to judge the relative position of the interaction in relation to the system state. This could be related to the foam aspect of the prototype, as it is hard to judge when foam is fully compressed. This could affect the ability to reach the smaller nibs or brighter colours, as the force-based sensels do not have limits like their slider counterparts. This also raises the issue of the user’s strength and stamina required to hold the selections. To keep the selection maintained, the user is required to balance their finger in the selected area, which can be difficult and uncomfortable. This is different to interactions with sliders, where once the selection is performed it stays in position. Participants perceived that they were more accurate using the GUI as it was possible to see the state relative to the end points. Investigation into different materials would better support this form of input.

Combined with looking at the error percentage, we saw that participants rated the deformable lower when accuracy was a key element of the task, as opposed to the second freeform task where people had more artistic freedom. We saw in the interviews that despite people’s concerns for accuracy, they enjoyed the tangibility of the deformable, with three even stating it supported their artistic ability in the freeform task. The visual attention rating shows no significant difference, even though deformable interfaces can rank better for eyes-free use [14]. One reason for this could be that the task did not need continuous control. This gave participants time to look down even if this was not necessary. Another factor could be the noise of the deformable’s actuation drawing their attention. In the interview, participants described their interaction with the deformable as eyes-free despite the subjective ratings given.

Future Work
This preliminary study has raised several key points to consider for building the next stage of the deformable prototype. Some participants preferred GUI sliders because they could see the progress made. This benefit negated the eyes-free advantage of the deformable. In our original design, we wanted to see if the foam’s compression would communicate force progress, but based on feedback this was not always successful. This gives us our next direction – to look at dynamically changing material that also holds its state based on the movement when interacting. The painting scenario can be refined so that users squeeze the nib to a certain shape, and then the sensel can hold this shape. This means that when users return they can feel and adjust the shape directly. If the shape then needs to reset, the computer can actuate it back to its original form. A further benefit of this design would be variable friction. This would enable the sensel to be harder or easier to push or squeeze. This dynamic alteration could help users judge the position more easily. For example, when nearing full saturation of a paint’s colour, the sensel could be harder to push.

Conclusion
This work has demonstrated an early exploration into dynamic force-based controls for digital painting. We conclude that participants are not yet able to use our deformable prototype as accurately or as quickly as sliders on a touch screen. Despite this, many of the participants enjoyed using the new interface. In interviews, they highlighted the advantages they saw and future uses. This study has provided us with valuable feedback, giving suggestions to improve our deformable prototype, and providing the next direction in bringing tangibility to digital painting.

Acknowledgments
This work was funded by EPSRC grants EP/N013948/1 and EP/M00421X/1.

References

[1] Loraine Clarke and Eva Hornecker. 2012. Designing and Studying a Multimodal Painting Installation in a Cultural Centre for Children. In *Fourth International Workshop on Physicality*. 28–31.

[2] Sean Follmer, Daniel Leithinger, Alex Olwal, Akimitsu Hogge, and Hiroshi Ishii. 2013. inFORM: Dynamic Physical Affordances and Constraints Through Shape and Object Actuation. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. ACM, New York, NY, USA, 417–426. DOI:http://dx.doi.org/10.1145/2501988.2502032

[3] Seongkook Heo and Geehyuk Lee. 2011. Force Gestures: Augmented Touch Screen Gestures Using Normal and Tangential Force. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11)*. ACM, New York, NY, USA, 1909–1914. DOI:http://dx.doi.org/10.1145/1979742.1979895

[4] Yuki Hirobe, Takumi Yoshida, Shinobu Kuroki, Kouta Minamizawa, Katsunari Sato, and Susumu Tachi. 2010. Colorful Touch Palette. In *ACM SIGGRAPH 2010 Emerging Technologies (SIGGRAPH '10)*. ACM, New York, NY, USA, Article 10, 1 pages. DOI:http://dx.doi.org/10.1145/1836821.1836831

[5] Yvonne Jansen, Thorsten Karrer, and Jan Borchers. 2010. MudPad: A Tactile Memory Game. In *ACM International Conference on Interactive Tabletops and Surfaces (ITS '10)*. ACM, New York, NY, USA, 306–306. DOI:http://dx.doi.org/10.1145/1936652.1936734

[6] Daniel F. Keefe, Daniel Acevedo Feliz, Tomer Moscovich, David H. Laidlaw, and Joseph J. LaViola, Jr. 2001. CavePainting: A Fully Immersive 3D Artistic Medium and Interactive Experience. In *Proceedings of the 2001 Symposium on Interactive 3D Graphics (I3D '01)*. ACM, New York, NY, USA, 85–93. DOI:http://dx.doi.org/10.1145/364338.364370

[7] Bhoram Lee, Hyunjeong Lee, Soo-Chul Lim, Hyungkew Lee, Seungju Han, and Joonah Park. 2012. Evaluation of Human Tangential Force Input Performance. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 3121–3130. DOI:http://dx.doi.org/10.1145/2207676.2208727

[8] Daniel Leithinger, Sean Follmer, Alex Olwal, and Hiroshi Ishii. 2014. Physical Telepresence: Shape Capture and Display for Embodied, Computer-mediated Remote Collaboration. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology (UIST '14)*. ACM, New York, NY, USA, 461–470. DOI:http://dx.doi.org/10.1145/2642918.2647377

[9] G. Michelitsch, J. Williams, M. Osen, B. Jimenez, and S. Rapp. 2004. Haptic Chameleon: A New Concept of Shape-changing User Interface Controls with Force Feedback. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems (CHI EA '04)*. ACM, New York, NY, USA, 1305–1308. DOI:http://dx.doi.org/10.1145/985921.986050

[10] Margaret R. Minsky. 1984. Manipulating Simulated Objects with Real-world Gestures Using a Force and Position Sensitive Screen. *SIGGRAPH Comput. Graph.* 18, 3 (Jan. 1984), 195–203. DOI:http://dx.doi.org/10.1145/964965.808598

[11] Ken Nakagaki, Luke Vink, Jared Counts, Daniel Windham, Daniel Leithinger, Sean Follmer, and Hiroshi Ishii. 2016. Materiable: Rendering Dynamic Material Properties in Response to Direct Physical Touch with Shape Changing Interfaces. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 2764–2772. DOI:http://dx.doi.org/10.1145/2858036.2858104

[12] Ivan Poupyrev, Tatsushi Nashida, Shigeaki Maruyama, Jun Rekimoto, and Yasufumi Yamaji. 2004. Lumen: Interactive Visual and Shape Display for Calm Computing. In *ACM SIGGRAPH 2004 Emerging Technologies (SIGGRAPH '04)*. ACM, New York, NY, USA, 17. DOI:http://dx.doi.org/10.1145/1186155.1186173

[13] Ivan Poupyrev, Tatsushi Nashida, and Makoto Okabe. 2007. Actuation and Tangible User Interfaces: The Vaucanson Duck, Robots, and Shape Displays. In *Proceedings of the 1st International Conference on Tangible and Embedded Interaction (TEI '07)*. ACM, New York, NY, USA, 205–212. DOI:http://dx.doi.org/10.1145/1226969.1227012

[14] Simon Robinson, Céline Coutrix, Jennifer Pearson, Juan Rosso, Matheus Fernandes Torquato, Laurence Nigay, and Matt Jones. 2016. Emergeables: Deformable Displays for Continuous Eyes-Free Mobile Interaction. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 3793–3805. DOI:http://dx.doi.org/10.1145/2858036.2858097

[15] Ilya Rosenberg and Ken Perlin. 2009. The UnMousePad: An Interpolating Multi-touch Force-sensing Input Pad. *ACM Trans. Graph.* 28, 3, Article 65 (July 2009), 9 pages. DOI:http://dx.doi.org/10.1145/1531326.1531371

[16] Anne Roudaut, Abhijit Karnik, Markus Löchtefeld, and Sriram Subramanian. 2013. Morphees: Toward High "Shape Resolution" in Self-actuated Flexible Mobile Devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 593–602. DOI:http://dx.doi.org/10.1145/2470654.2470738

[17] Faisal Taher, Jason Alexander, John Hardy, and Eduardo Velloso. 2014. An Empirical Characterization of Touch-Gesture Input-Force on Mobile Devices. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces (ITS '14)*. ACM, New York, NY, USA, 195–204. DOI:http://dx.doi.org/10.1145/2669485.2669515

[18] Jessica Tsimeris, Colin Dedman, Michael Broughton, and Tom Gedeon. 2013. ForceForm: A Dynamically Deformable Interactive Surface. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces (ITS '13)*. ACM, New York, NY, USA, 175–178. DOI:http://dx.doi.org/10.1145/2512349.2512807

[19] Bret Victor. 2016. Seeing Spaces. (2016). http://worrydream.com/SeeingSpaces/

[20] Luke Vink, Viirj Kan, Ken Nakagaki, Daniel Leithinger, Sean Follmer, Philipp Schoessler, Amit Zoran, and Hiroshi Ishii. 2015. TRANSFORM As Adaptive and Dynamic Furniture. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15)*. ACM, New York, NY, USA, 183–183. DOI:http://dx.doi.org/10.1145/2702613.2732494