Origami Simulator: a Multi-Touch Experience

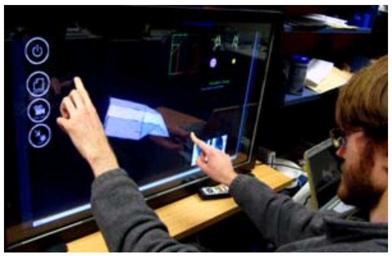

Figure 1. The two touch origami.

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Abstract
We present a 3D origami simulator with multi-touch interaction. This is a preliminary exploration of manipulating 3D models with multi-touch. Following a user centered approach, we analyzed how people make paper origami models and mapped the common actions into two-touch gestures. The user study suggested that people enjoyed the simulator and think the techniques can be applied to other 3D modeling environments.

Keywords
Multi-touch interaction, 3D manipulation.

ACM Classification Keywords
H.5.2 User Interfaces: *Input devices and strategies, Interaction styles*

Introduction
3D modelling tools are for experts: this is the common perception among people. Traditionally the mapping of the 3D interaction in a virtual world to the 2D interaction on a monitor is done via mouse and keyboard input. Since these devices limit the degrees of freedom users have [5] 3D tools typically include many modes, views and menu functions to achieve model manipulation. The complex interaction decreases the usability and confuses users.

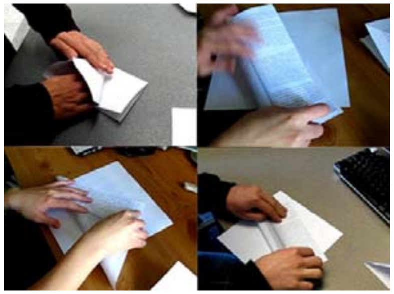

Figure 2. The study of how people fold.

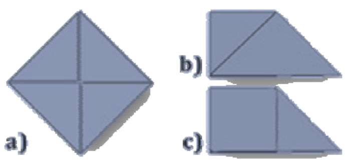

Figure 3. Target origami shapes.

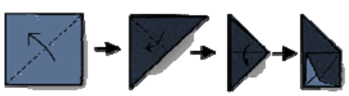

Figure 4. One of the folding instructions.

However, 3D modelling is becoming more widely used. It has long been an essential part of architecture and engineering. New games leverage improved graphics capabilities to include complex 3D spaces. More people interacting with 3D spaces is driving research into more natural interaction methods. Alternative devices have been developed, however many are not intuitive to use.

Ideally, interacting with a virtual 3D object should be intuitive, mapping closely to the actions for the physical equivalent, for example shaping clay or folding paper. We investigate the use of a multi-touch screen to achieve this goal. This technology has penetrated the hardware market [2, 4], and it has proved to be effective for 2D interactions. Its advantages of direct interaction with the display and bimanual input attracts research to improve its intuitiveness [1, 7]. Although Steinicke et al. [8] discussed the limitations and possible solutions to multi-touching 3D data, and Hancock et al. [3] explored the application of rotating and translating 3D objects with multi-touch, no manipulation method is yet explored.

The objective of this project is to use multi-touch to increase the efficacy of 3D model interactions. We selected origami as the context because it is relatively simple to model, yet provides many interaction opportunities. Furthermore because most people have some paper-folding skills evaluations are not limited to experts. To focus on the interaction rather than the software modelling, our first step was a simulator with the functionality for users to build a paper plane.

Interaction Requirements Discovery

Intuitive interaction often comes from mimicking how people perform actions in the real world. Multi-touch screens provide opportunities for bimanual input such that natural interaction becomes possible, as people often use two hands to manipulate real-world objects.

From origami books we found that there are many standard folding methods (and some rarer artistic folds). Hovever, most methods can be categorized as a “fold”, to create a fold line, or a “tuck”, where a part of the paper is pressed between two other sides.

The tutorials revealed the common techniques, but not how people perform them. We collected performance information through a three part observation study of ten people. First participants were asked to fold three simple origami shapes (Figure 3) that require various different folds and tucks. Folding instructions were drawn on paper (Figure 4), without describing how exactly folding should be done. Second, participants were asked to fold a paper plane, as this is what users should be able to create with our simulator. Finally, they were asked to create the most complex origami object they knew. This allowed us to collect rich information on paper folding behaviour. Participants worked on a tabletop and were videoed.

Fold was universally achieved by dragging a corner to another corner, or dragging one edge to another edge. We refer to these two types of folding as point-to-point and line-to-line. A line can be an edge or a crease line, while a point can be a corner or an intersection point of multiple lines (Figure 5). Most participants did not know how to tuck and the rest performed tucks in a wide variety of ways. Many other actions were observed in the study. The main ones were flipping the paper over and rotating the paper.

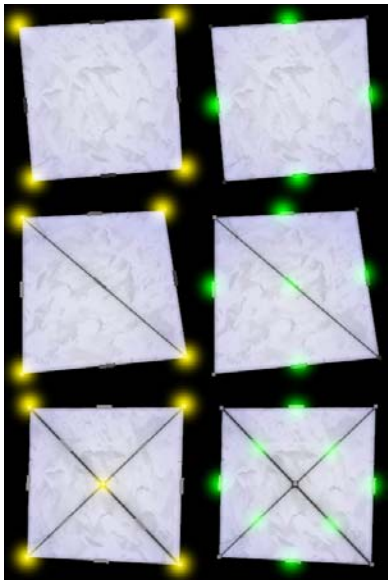

Figure 5. Paper model
Left column yellow parts are points, right column green parts are lines. A paper initially consists of four points and four lines, when two lines cross each other, a point will be dynamically generated at the intersection.

Figure 6. Finger-tip and knuckle

Prototype System

A NextWindow [6] two-point touch screen was used. It is a 40” wide overlay which is placed on top of a large screen; its API returns the position and size of both touches. To utilize it, we first built a 3D environment containing a paper model that could be manipulated.

Building the 3D environment

The paper model was built upon vertices, which define polygon meshes. The number of vertices starts with four, and increases with additional folds, as shown in Figure 5. Lighting and 2D texture adds to the paper metaphor of the model. Points (vertices) and lines (edges or fold-lines) can be selected to simulate point-to-point or line-to-line folds.

A physics engine was used to further simulate the real world behavior. It calculates the movement of each vertex, which not only made the reaction of the paper more plausible, but also reduced the amount of programming and user work required, as they enabled some real world manipulation strategies [9].

Functionality opportunities

We define functionality opportunities as actions to which functions can be directly assigned, without an abstract gesture. “On paper” (point or line selected) and “not on paper” is a binary choice: combining this with two touches gives four functionality opportunities, including on paper with one finger and not-on paper with two fingers. To achieve more basic touch functions two different touch sizes, small and large, are used, which increased the functionality opportunities to eight.

Two obstacles were encountered when detecting the size of a touch. First, due to the hardware limitations, the size of the second touch point is often incorrectly detected. Second, friction can make it hard to move a whole hand on the glass surface. The first problem caused us to abandon using size as a variable for two touch actions, and after many experiments, we found using knuckles, as shown in Figure 10, can greatly reduce the friction problem.

Interaction with the simulator

Many techniques exist in origami, but a maximum of six functional opportunities existed. We chose to support drag, fold, tuck and look around because they are most common. Fold and tuck are the essential actions of origami. Drag is the action of holding parts of the paper and pulling them together or apart. Look around involves examining the paper from a different angle or zooming, which can result in better view which, in turn, can reduce the difficulty of the folding process.

We attempted to simulate the real world actions; however, this goal could not be achieved for some actions since we were limited by the 2D screen and the limited functional opportunities. For example, point-to-point fold in the real world is normally done by pressing one finger on a corner to stabilize the paper, pinching another corner of the paper with the thumb and first finger of the other hand and moving it to the first corner, holding them together with the first finger and creating a crease line with the second hand. Such folds involve many complex actions and movements in 3D space. Although we attempted firstly to directly simulate these actions, because finger on 2D screen is different from manipulating real paper, they were not intuitive; furthermore, the complex interaction methods prevented us from implementing them with our hardware.

Figure 7. Drag to rotate.

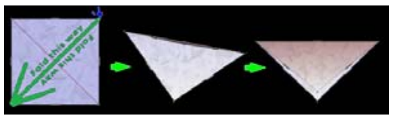

Figure 8. Folding a triangle.

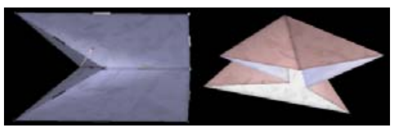

Figure 9. Tucking example.

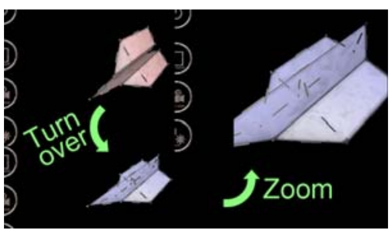

Figure 10. Turning the paper over and zoom in.

Taking a user centered approach we first analyzed the frequency of actions. Drag and look around were the most common ones; they are given the simplest gesture – finger-tip on screen. They are distinguished by whether the finger is touching on paper (drag) or not (look around). Certain drags are mapped to two touches, such as opening the folded paper. Furthermore standard interaction techniques were adopted: for look around, we use the metaphor of rotating the camera angle; zoom uses two finger look around.

Fold is considered to be dragging paper points together, however since the model does not support bending, the full range of real world actions could not be supported. Our observations suggest that only point-to-point and line-to-line fold occur in simple origami. We simplified the fold action, so it can be done with only one knuckle, by selecting one point/line and dragging the knuckle to another point/line; the folding takes effect when the touch is released. Although different from its real world counterpart, it is intuitive to learn and the best choice within the hardware environment. We specifically built tuck but found that with the combination of 3D model and physics engine, tucking can be achieved by simply dragging the paper around fold lines.

	On paper		Off paper	
	One	Two	One	Two
Finger-tip	Drag		Orientation	Zoom
Knuckle	Fold	--	Functional gesture	--

Table 1. The mapping of direct manipulations

In summary there are eight direct manipulation possibilities, however double knuckle was not used because of size detection errors when two touches are presented. The functions mapping are shown in Table 1.

The implemented common functions allow people to interact with the paper model and build origami. To expand the functionality, button and functional gestures are provided. Functions such as close application, new paper, reorient are implemented as buttons. To minimise screen clutter more advanced functions are supported by gestures. The gestures are triggered by creating a path on screen; a path can be as simple as a movement towards left, or a combination of several simple paths such as left-up-down sequence. Functions such as redo/undo and beautify the paper model are implemented as functional gestures.

To evaluate the effect of using size to differentiate actions, we introduced a special button as an alternative. By tapping the button users can switch between "finger-tip" and "knuckle" interactions, without the need to worry about their finger status. In the study described below we called this 'button mode'.

Initial user evaluation

A user evaluation was conducted with nine student participants who had diverse origami skills and digital 3D modeling experience. After a pre-training session, each participant was asked to complete three tasks: fold a basic shape and unfold; fold and unfold the same shape with button mode; and fold a paper plane. Instructions and real origami products were available to them for reference.

The first task was designed to test if the interaction system feels natural. The second task was designed to test if participants prefer to distinguish the touch mode

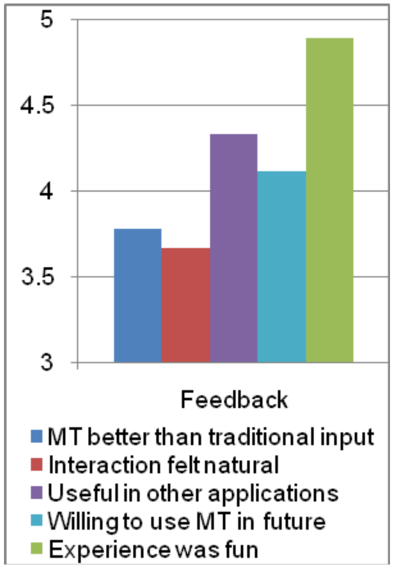

Figure 11. General feedback

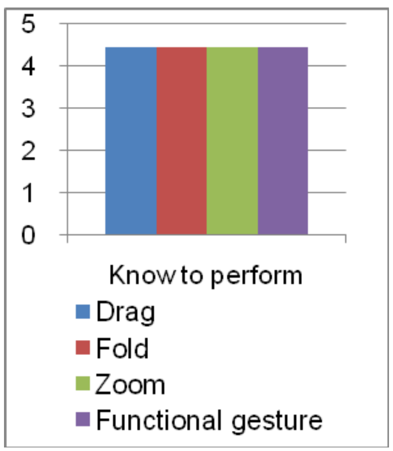

Figure 12. Ease of use

by size differences or button status. The last task was designed to test if this simulator can be used to perform complex simulation involving numerous paper orientation and manipulation skills. A post-task questionnaire gathered opinions about task enjoyment and intuitiveness of interaction on a 5 point Likert scale, where 5 means strongly agree and 3 indicates neutral.

Results

The general feedback (Figure 11) suggests that participants are positive about the simulator. The lowest mean rating at 3.67 was "the interaction felt natural". Implemented gestures were intuitive (Figure 12) with all participants able to perform drag, fold, zoom and functional gestures after the simple demonstration. All participants were able to create the exact crease patterns required for a paper plane, and seven of them completed it with the correct shape and orientation.

An obvious result is that the experiment was highly enjoyable, with a rating of 4.89. Furthermore a rating of 4.33 suggests that participants believe the multi-touch technology can be useful to other applications, the rating for use of multi-touch technology is 4.11.

In comparing the button and size mode a rating of 3.67 suggested that button mode was more intuitive than the size mode. Discussions with the participants suggested that the main reason for this was because the size detection is error prone. It requires participants to learn the correct way of touching, thus reduced the intuitiveness. However we observed that most people completed the third task with size mode, this is in contradiction to them thinking that button mode was more intuitive. Most said this was because "it is faster".

Discussion and future work

Our prototype and the user evaluation suggest that multi-touch technology is certainly applicable for 3D modelling interactions. Furthermore we found that multi-touch and physics simulation complemented each other. As described, complex functions such as tuck can be performed with the support of the physics engine, without the need to implement them explicitly.

Our prototype has limited capabilities. In particular it would feel more natural if paper thickness, surface interaction detection and real time curvature were implemented. These constraints lead to some user confusion of orientation and an unnatural look when a participant tries to create origami. We expect a greater user acceptance after these features are modelled.

Most of the implemented interaction methods do not directly follow the real world interactions. Part of the reason is the limitations of the hardware, but the main reason is that multi-touch simulation is still different from interacting with real objects. Multi-touch interaction is limited by the 2D interface. We noted people tend to express a preference for the traditional modal interactions provided as the 'button mode' to different touch sizes, even if they found it is less efficient. The reason may be that the simulator is a digital platform and participants in the experiment were digital natives who are used to traditional input methods. As multi-touch technology is more widely deployed, it will be interesting to see how users adapt to such interaction opportunities.

The design methodology we adopted was certainly helpful. The observation study exposed the most important functions and the priorities. The observations

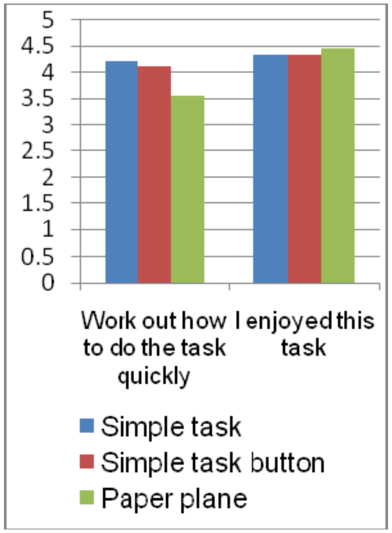

Figure 13. Task comparison

lead to us developing a strong gesture scenario. Although some actions may not be ideal, they can be shaped into better gestures through hardware and design evolution. The metaphor we evolved from the observation study captured the essence of origami.

Our implementation of different touch sizes created some training difficulties, because the "correct" way is unintuitive. A hardware platform with more reliable size detection or *n* touch detection points could lead to more intuitive alternative input methods.

Although this project was conducted on origami, which is relatively simple, we believe the result can be applied to more complex areas, such as engineering or architectural design. As shown in Table 1, the combination of touch numbers, size and position introduced eight different direct manipulation opportunities, which means the possible function slots is equal to the product of these three variables. Given a ten finger touch screen, even if the level of size and touch position remains binary, it will be able to provide 40 different direct manipulation opportunities. Touch positions naturally increase with the complexity of problem, for example, adding scissors into the simulator will provide more positions to touch, which will result in a more complex system. However, major improvements can occur with screens providing more touches or more accurate detection of size.

Conclusions

Multi-touch interaction is proving popular for 2D model interaction. We implemented and evaluated a 3D model which utilised multi-touch and physics simulation. People found the combination of the two technologies made the 3D interaction to be intuitive, visually plausible and enjoyable, and they believed that such technology can be applied to other 3D applications.

Acknowledgements

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