FLOWFIELD AND BEYOND: APPLYING PRESSURE-SENSITIVE MULTI-POINT TOUCHPAD INTERACTION

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ABSTRACT

In this paper, we discuss a new hand-gesture-based application, FlowField, which explores the use of pressure-sensitive multi-point touchpad (multi-touch) interaction. FlowField allows participants to interact using their whole hand with a flow of circulating particles, providing visual and auditory feedback. Limitations of the raw data mapping used in FlowField motivated work on applying interpolation techniques to improve the data representation. Thus far, bicubic interpolation provides the most effective method for initial processing. We observed two factors limiting the quality of the representation: the spacing of the sensors, and the pressure-distributing property of the touchpad surface.

1. INTRODUCTION

Single-point touchpads are most often found in mobile computers as a space-saving substitute for a mouse. As a consequence, these touchpads have a small footprint and provide binary pressure input (touching/non-touching) for a single (x,y) coordinate constrained on a planar surface. For pointing tasks, this is adequate; in fact some people prefer a touchpad to a mouse.

However, the human hand is capable of more than just simple pointing tasks. It is free to move in space and assume a wide variety of shapes and gestures. Generally, the full extent of human manual dexterity is rarely used for human computer interaction.

Unfortunately, there has been a "chicken-and-egg" dilemma with using whole-hand input for HCI: on the one hand, input devices supporting whole-hand input have not been available on a large scale; on the other, applications do not exist for whole-hand input, so such devices have not been created.

To contribute to changing this situation, we are developing applications that specifically explores what whole-hand input can be used for beyond pointing and selecting. In particular we chose an application that cannot be performed easily with single-point input, which is difficult since this is the predominant interaction method for computer applications.

Our application, FlowField, focuses on a task where multiple objects are manipulated as a coherent whole. We anticipate that applications which use the whole hand for manipulation in a consistent, engaging fashion will lead to satisfying interfaces [3]. We explore this aspect in FlowField.

We use the MTC Express (fig. 1) by Tactex Controls, Inc. as the input device. It is a pressure- and multiple point-sensitive touchpad intended for use as computer peripheral. The sensing surface is larger than laptop touchpads, suitable for whole-hand, multiple-finger input.

A metaphor of fingers interrupting a continuous flow of water was evoked to allow participants to use the MTC Express as a multi-point input device. This metaphor was chosen to emphasize the effectiveness of multi-point input over single-point input.

Figure 1: MTC Express

In this paper, we describe the FlowField interactive system and some results from participant studies. We then outline a major limitation of the mapping used in the system and how it can be mitigated. We describe our efforts with applying interpolation techniques to the raw input data in order to produce a better representation of the pressured applied on the sensing surface.

Finally, we outline some of the future work that we hope will further refine the input representations and provide new features such as contours and predictive tracking.

2. RELATED WORK

Multi-point pressure-sensitive touchpad technologies have not been explored as extensively as their single-point counterparts. The work by Lee et al. [4] is the earliest example of such a device, albeit a prototype. Lee refers to this technology as "multi-touch", a term also used in describing the MTC Express.

A more recent development is the TouchStream technology from FingerWorks, developed by Westerman and Elias. TouchStream products comprise of multi-point touch surfaces that recognize finger locations and touch state for the purpose of keyless keyboarding. The embedded sensors capture images of the hands and fingers as they approach the surface.

Oka et al. propose a vision-based system for tracking multiple fingertips [5]. This is part of an augmented desk interface and makes use of infrared cameras to overcome issues resulting from to changing lighting conditions. Hidden Markov Models are used to perform fingertip motion prediction which aids in tracking.

Rekimoto's SmartSkin [6] also performs multi-point tracking. Using capacitive sensing, a scalable array of sensors can perform hand-tracking in two dimensions and builds a pseudo-pressure profile of the hand based on its proximity to the sensing surface. In contrast, the MTC Express measures applied pressure.

Pressure-sensitive input surfaces can be found in Wacom's line of drawing tablets. Such a device is well-suited for writing and drawing tasks requiring high input resolution, though it has no multiple-point support.

The technology behind the MTC Express is also being used in a variety of devices and applications, including audio mixers (M-Audio Surface One) and expressive virtual musical instruments [2]. There is also work by Schiphorst et al. using the MTC Express to explore the qualitative aspect of touch [7]; gestures are recognized and interpreted in the context of an artificial life environment.

Two interactive art installations demonstrate particle manipulation by silhouettes similar to FlowField: Text Rain by Utterback and Achituv [9], and Sand installation for the Shadow Garden by Simpson [8].

3. MTC EXPRESS

The MTC Express (fig. 1) is a compact touchpad with a serial interface. The black sensing surface is approximately 19cm by 17cm, and is made of a firm rubber substance. The sensing surface has 72 sensors embedded underneath, called Taxels, which measure applied pressure (8-bit). The Taxels are spaced approximately 1cm apart in a 12 by 6 grid.

Data sampling rates may be set at between 35Hz and 200Hz, with rates greater than 70Hz possible using data compression. We developed a Linux driver for use with our system as only Windows and Macintosh APIs are provided.

4. FLOWFIELD

The FlowField system [1] is an interactive art piece, conceived by Fels and Schiphorst, in which a dynamic particle simulation immerses participants in a CAVE Automatic Virtual Environment (CAVE™). The participant holds the MTC Express in one hand and manipulates it with the other for input. Simulated physical particles flow in a closed cylindrical path (fig. 3) around the participant, who feels he/she is standing inside this virtual cylinder of particles due to the stereoscopic graphics projected in the CAVE. A block diagram of the system is shown in figure 2 showing the virtual cylinder and the participant inside it.

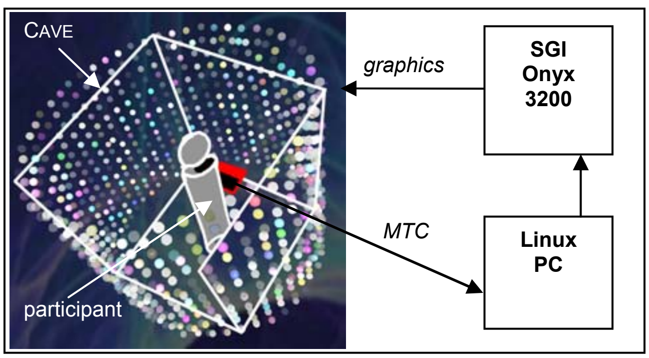


Figure 2: FlowField system diagram

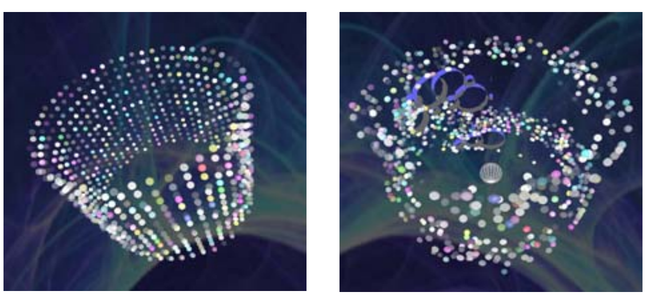


Figure 3: Cylindrical particle field (left), obstructions seen disrupting particle flow (right)

Figure 4: Applying pressure to the MTC Express (left) and resulting obstructions (right)

As the input pad surface is two-dimensional, positional input from the touchpad is constrained to a 2D surface within the environment. We use a one-to-one mapping between the position of a Taxel and a rectangular patch on the curved surface of cylinder. The positions in the scene are fixed so they do not change even if the MTC express is moved[1]. While this is an indirect mapping, we anticipated the one-to-one nature and mode-less interaction would enable participants to easily grasp the relationship between hand gestures and their effects on the system.

The third dimension of applied pressure is also used to control the flow of particles. The participant's applied pressure on a Taxel on the input surface is mapped to the diameter of a circular obstruction that appears in a fixed location and disturbs the path of the flowing particles. This cylinders corresponding to a person touching the pad is shown in figure 4, though normally, the cylinders are invisible so only the disturbance of the flow is seen. These obstructions affect the flow of the particles, deflecting them according to a simple dynamic physical model, in which a particle moves indefinitely in one direction unless it collides with another particle or an obstruction. Resultant velocities of particles after collision are computed based on impulse transfer. The effect from the participant's point of view is that touching the pad is like moving fingers through running water.

5. TASK DISCUSSION

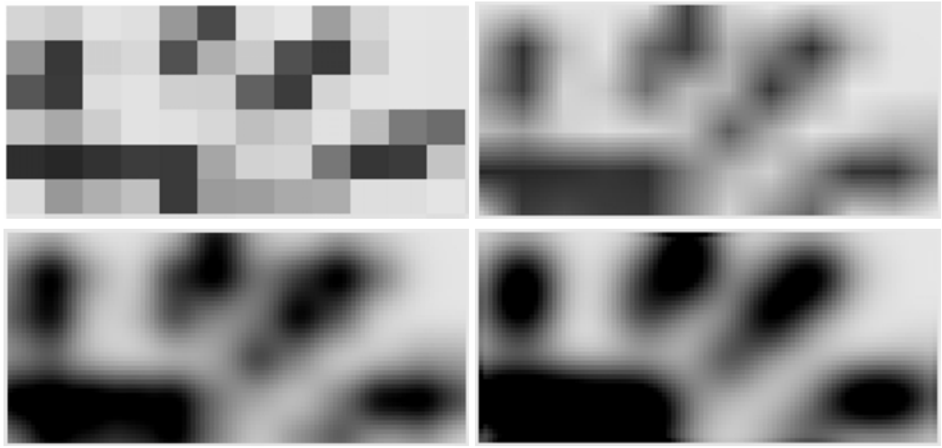
There are several reasons why this task is difficult to do with a single-point tracking device, such as those used for VR navigation. Most important, though, is that this task is designed around a "finger<u>s</u>-in-water" metaphor. A single point interface allows for only a single finger to be in the "water" at any moment in time. For example, a wand tracker functions as a 3D analogue to the mouse, returning coordinates for a single point. Used in the most direct way, an obstruction is created at the single point corresponding to the location of the wand. This type of interaction does not allow for complex spatial arrangement of obstructions. Furthermore, sustaining complex patterns in the flow would also be very difficult to accomplish.

Instead, the type of manipulation used in FlowField is set up to take advantage of the way people use their hands to manipulate collections of objects. Thus, the whole-hand sensing of the MTC Express provides the appropriate input for a "fingers-in-water" metaphor. Conversely, single-point input devices are appropriate for "finger-in-water" metaphor.

Another favourable property of the MTC Express is its physical surface, which allows for more precise and repeatable positioning of the hand and fingers. This surface provides the participant an idea of how her hand is configured. This combined with the human sense of proprioception gives the precision and repeatability more difficult with a free-gesturing interface typical of glove- and wand-based devices.

The cylindrical obstruction scheme was chosen as a simple means for mapping the shape of the hand based on applied pressure. Understandably, the impression of the hand in the scene

[1] We did not investigate mapping the movement of the whole pad to actions in the environment. This feature is easy to add but is not necessary for this discussion.



does not precisely recreate the shape of the participants' actual hand; however, it is sufficient for a strong impact.

6. RESULTS AND OBSERVATIONS

FlowField was demonstrated in the CAVE at the New Media Innovation Centre Immersive Media Lab facility. Over several months, including an open house event, many visitors had the chance to experience FlowField.

From an experiential standpoint, FlowField was well received as an engaging, dynamic showcase of both the CAVE and interaction with the MTC Express.

We conducted a small user study with ten subjects to substantiate the anecdotal reports. We sought to evaluate subjects' approach to using the touchpad interface and how they felt about the input device's effectiveness in facilitating the interactive task. Each subject was asked to simply to enter the installation and utilize the MTC Express any way they wished. To supplement the experimenter observations, subjects were also asked to complete a brief questionnaire after their participation.

The questionnaire posed several statements to which the subjects would rank on a 5-point scale: strongly agree (SA), mildly agree (MA), neutral (N), mildly disagree (MD), strongly disagree (SD).

Every subject, without exception, initially used a single finger to touch the touchpad, even after the multi-point property had been introduced. From the questionnaire responses, all subjects had worked with laptop touchpads before, so their approach to touchpad usage is not surprising.

The subjects eventually discovered the multi-point capability and how to apply it to the system. They had little difficulty understanding that the applied pressure of their hand affected the obstruction sizes (6SA, 2MA, 2N). This effect is not obvious a priori considering the indirect mapping and low resolution of input data (1cm sampling interval).

In general, the questionnaire results indicated that the provided interface worked well for performing the flow manipulation (4SA, 3MA, 2N), and that they enjoyed their experience (7SA, 3MA). While they were positive about the usefulness of the MTC Express' unique properties, many of them maintained that there were other ways the task could be performed (3SA, 3MA, 3N).

Aside from aesthetic and artistic considerations stemming from FlowField's role as an art piece, the choice of mapping is the obvious area of interest for understanding how well multi-point input is perceived. The main problem noticed by participants was that the regularly spaced obstructions only provide an appreciable barrier when the diameters of a cluster of obstructions are large, occurring when a large area of pressure is applied. With the current mapping, it is difficult to produce several areas of small obstructions the same way several fingers would do so in water.

In order to achieve anything more than flow interruption by large barriers, we realized that a different strategy for mapping pressure data is required. For example, an outline representing the precise shape of the hand pressing against the touchpad would be useful. To do this, we have begun investigating interpolation techniques to smooth the coarse input data. The idea is to use the smoothed data to extract hand contours that can be used for "fingers-in-water" manipulation.

7. INTERPOLATION TECHNIQUES

The goal for our interpolation filters is to produce a more accurate representation of the shape of the hand (or object) being pressed on the MTC Express. For this, we desire a high-resolution pressure profile of the hand. Limitations of the MTC Express make this difficult.

Applying interpolation would considerably improve on the 12 by 6 effective resolution of the input data set. Most interpolation techniques are often applied in the context of image processing, where signals have been conditioned to obey the Nyquist theorem. Unfortunately, the 1cm sampling of the MTC Express would, by Nyquist, preclude perfect reconstruction of objects with a width less than 2cm (in the simplest 1D case), such as fingers.

Several interpolation techniques were applied to the raw data and the results of each are presented in figure 5. Three algorithms are compared: bilinear, bicubic, and Gaussian. A nearest-neighbour interpolation is also shown for comparison where each tile effectively represents one Taxel value.

Each screenshot has an upsampled resolution of 108 by 54, translating to a simulated sampling interval of 1.1mm.

8. DISCUSSION

The interpolation results were evaluated qualitatively by eye. Any result that produced representations that are more suggestive of a hand shape would be better than the raw data representation. A quantitative evaluation may involve computing the error between the interpolated images with the actual data at the same sampling, something not obtainable from the MTC Express.

The bilinear interpolation technique did not return very good results, with the Taxel rows and columns readily visible and overemphasized. However, when compared with the raw data representation, finger shapes are more readily seen.

The result from Gaussian interpolation shows an acceptable hand shape. This representation is smoother, due in part to the blurring property of the algorithm. The aggregate shapes can still be seen as being composed by patches centred at Taxels, but the effect is not as pronounced.

Bicubic interpolation produces a representation that clearly shows a blurry hand. Dark areas here are slightly thicker than their Gaussian-interpolated counterparts. Thus the shapes have even more continuity with fewer artifacts.

Bilinear interpolation is by far the quickest algorithm, followed closely by Gaussian, but the bicubic algorithm runs over

60% slower. Nevertheless, interactive frame rates for all three algorithms are still achieved using consumer-grade equipment.

An artifact of the sparseness of the Taxel spacing can be seen when moving a finger across the surface. When the finger is located directly over the Taxels, then the interpolated shape is well-defined. When the finger moves in between Taxels, the shape becomes less well-defined, even though the applied pressure is the same.

The interpolation filters are not able to compensate for this while still maintaining a distinct shape for fingers. In the end, as a compromise, the effect is a phenomenon where shapes with a small width, such as those produced by fingers, are alternately represented by strongly or weakly defined areas as it moves across the surface. The shapes are seen to be fading and recoalescing, instead of smoothly translating. A higher sampling interval of the pressure sensors should eliminate this.

Another aspect of the MTC Express that affects the correspondence between input pressure and output data is the rubber material of the sensing surface. This surface is actually quite firm and thus spreads the applied pressure considerably. As a result, any area of contact affects not only the Taxels immediately underneath, but also the neighbouring Taxels. The material has not been characterized yet so compensating for its low-pass filter effect to determine the shape of the object touching the surface is not yet possible.

This property, when combined with the inherent blurring introduced by Gaussian or bicubic interpolation, contributes to smooth gradients between dark and light areas, and therefore poorly-defined edges. Furthermore, this is exacerbated by the sparseness of the Taxels. It would be interesting to consider the effects of interpolation without the force-distributing rubber layer.

9. FUTURE WORK

At this point, we have a satisfactory interpolated representation that is qualitatively better than the original Taxels for extracting shape information. There remain several areas we are exploring to further improve the interpolation of the raw data and ultimately, to extract the shape contour:

- Applying filtering and edge detection to sharpen the pressure profile and to better identify edges;
- Varying the response curve of the input pressure, emphasizing high pressures and minimizing lower values;
- Making an assumption on the minimum width of possible objects (i.e. fingers), to better resolve them when they are placed between Taxels;
- Using motion prediction as a means to choose between several possible pressure profiles given the current raw data set and temporally preceding pressure information.

From the interpolated values, we can look at generating closed-curve outlines that represent the cross-section of the hand touching the surface. Established image-processing techniques can now be readily applied since the pressure profile is of higher resolution.

Eventually, the results from interpolation and curve-fitting will produce a far superior input for the FlowField system. Imagine a faithful representation of the participant's hand and fingers interact realistically with the flowing particles.

With this representation, applications can be developed that take advantage of multiple-finger and hand-shape tracking. In addition to uses of the empirical data, gestures and intentionality can be derived and explored, especially when dealing with touch, where caress can be a powerful form of expression.

10. CONCLUSION

This paper described a new interface that uses whole-hand input measured by a multi-touch input device to manipulate a simulation of moving particles. The application investigated how multi-touch input can be applied to manipulation through a "fingers-in-water" metaphor. Participant testimonies and a user study corroborated the effectiveness of the interface, but also uncovered deficiencies in the current state-of-the-art in multi-touch sensing. Various interpolation schemes were implemented to overcome these problems. Bicubic interpolation provided an effective means for providing smooth data that can be used for extracting shape contours from the pressure profile on the input surface. However, the limitations of the sensing technology remain a problem that interpolation filters alone will not solve.

The use of hand gestures for human-computer interaction still remains complicated for two main reasons: first, the input technologies are still not sufficient to accurately determine what a user's hands are doing, and second, the role of gesture is not understood well enough to make applications that effectively use gesture. In the domain of caress—that is, hand pressure applied on a 2D surface—we have begun to develop the techniques that will lead to a better understanding of the semantics of gestures and the technologies necessary to utilize them in applications.

FlowField has demonstrated that a "fingers-in-water" metaphor is one excellent choice for mapping caress in a satisfying and engaging way. Furthermore, improvements in the technology will allow this form of manipulation to be effectively used in other applications.

11. ACKNOWLEDGMENTS

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