FlexStylus: A Deformable Stylus for Digital Art

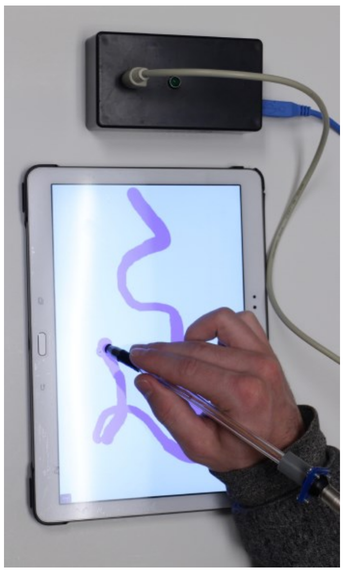

Figure 1: The FlexStylus system, demonstrating a mapping of absolute bend to line weight.

Nicholas Fellion
Carleton University
Ottawa, ON K1S 5B6, CA
Nicholas.fellion@carleton.ca

Alexander Keith Eady
Carleton University
Ottawa, ON K1S 5B6, CA
Alex.Eady@carleton.ca

Audrey Girouard
Carleton University
Ottawa, ON K1S 5B6, CA
Audrey.Girouard@carleton.ca

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Abstract
The FlexStylus is a prototype system that embeds sensors measuring analog flex input in a computer stylus. Through fiber optic sensing, the device detects both absolute extent and angle of flexion. The device was designed to allow these two channels of analog input, as well as derived parameters such as rate and relative motion, to augment the basic x/y functionality of a computer stylus. The goal of this augmentation is to improve a digital artist's ability to control their work through tactile manipulation, as well as expand the artist's range of expression and effects. We also introduce the use of flex input to create an additional pointing space, allowing for the execution of gestural drawing commands without moving the tip of the pen.

Author Keywords
Deformable user interfaces; bend gestures; augmented stylus; stylus design; tablet; HCI.

ACM Classification Keywords
H.5.m. Input devices and strategies

Introduction
Computer design software has replaced physical media in a large variety of creative contexts, such as graphic design, animation, and comic art. Yet, an advantageous aspect of physical media is the degree to which user

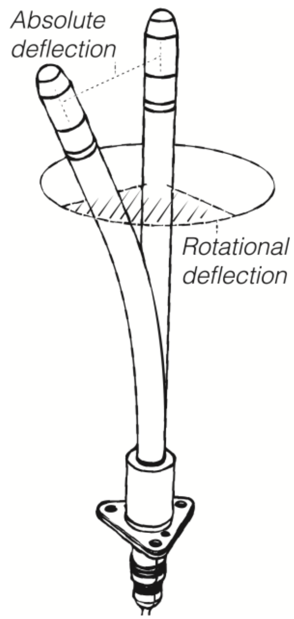

Figure 2: Illustrating the two parameters of bend input measured by the FlexStylus prototype: absolute and rotational deflection.

control is exerted over a wide variety of possible variants. The expert painter is occupied with countless subtleties: the tilt of the brush, the amount of tension in the hand, the texture of the paint. Comparatively, a digital artist has a narrow immediate range of physical influence over the behavior of their media.

To mimic physical tools, artists often use a stylus as an input method for artistic tasks. The stylus confers several advantages over other systems, such as track pads and mice, the main one being the ubiquity of the pen—learning how to hold a pen is a basic task taught in schools, and finely manipulating a pen, stylus, or brush is a muscle task with which many humans, especially artists, are relatively adept. The basic stylus does not, however, provide the degree of control over the behaviour of the medium that a physical tool, such as a brush or nib, provides.

Several prior projects focus on amending this problem by augmenting the stylus with additional types of input. The modes of input vary, but their associated interactions can be grouped into two categories: menu navigation or command interactions, during which the stylus nib remains static, and continuous parameter control, where x-y information is used simultaneously to the augmented input.

Bi et al. [5] created a system which detects pen roll, and studied how this input modality might be used in navigation and menu interactions. They also investigated how pen roll might augment x-y pen control, such as a system where the user can control the position and angle of curve control points simultaneously. They found that simultaneous roll and spatial interactions were possible, but associated with greater than 5 mm tip movement [5]. Song et al. [15] devised a multi-touch prototype called the MTPen, which augments the stylus using a wraparound multi-touch sensor, allowing users to perform gestures on the pen. The MTPen system discriminates between control configurations depending on how the user holds the pen. The MTPen also functions as an augmented stylus for continuous parameter control, where scrolling gestures on the body of the pen can be used to control drawing parameters. Several projects have also investigated tilt as a supplementary input modality for menu selection [16,21,22].

Researchers have also looked to reproduce analog artistic media. Otsuki et al.'s MAI [13] is a paintbrush-shaped device that uses sensors to the degree of pressure and angle applied to a flexible brush. It is specifically designed for emulating painting. This brush concept was also found in Liu and Gu's flexStroke [11], which used a jamming system with pneumatics to create a tip with varying flexibility.

Commercial styluses have also followed the pattern of augmenting x-y stylus input with additional methods of continuous parameter adjustment. These often consist of styli with pressure sensing capability [2,12,18], but there are other examples, such as a Wacom Airbrush Pen [19], which loosely emulates an airbrush through a top-mounted wheel control, and the Apple Pencil [2], which is capable of detecting tilt, and uses this as a simultaneous parametric control.

The FlexStylus prototype

We present FlexStylus, a flexible stylus that uses embedded optical sensors to detect two parameters of deflection, rotational and absolute (Figure 2). These flex inputs are used to augment the X-Y input of the stylus in order to add richness and depth to artistic projects. We believe that the continuous bidirectional nature of bend input, as well as the fact that this input can be supplied with subtle gestures of the hand while manipulating the pen in the x-y axis, makes it an ideal input modality for augmenting the traditional stylus. The combination of bend and angle detection gives bend gestures a high input bandwidth, and we hypothesize that this bandwidth can be exploited during x-y motion with minimal effect on tip position.

While based in the deformable user interaction domain, the FlexStylus departs from the traditional planar configuration of a large number of such devices, e.g. flexible displays or simulated flexible displays [1,8,10,20]. We suggest that deformation as a method of continuous input can be useful for applications outside of planar flexible devices with smartphone or tablet form factors. Researchers have begun to explore deformations on non planar devices within the domain of expressive musical interfaces [6,14,17]. These kinds of interactions are considered well-suited to musical interfaces as they are geared towards tactile expressivity and embodiment, and because their dynamic physical configurations can be used to represent sonic qualities [17].

Ahmaniemi et al. [1] conducted a study attempting to determine precisely which kinds of tasks are well suited to bend gestures. They determined that bend interactions were ideal for continuous control of a parameter, especially when that parameter is bipolar, and is associated with a central neutral state, such as for zooming and scaling. It is possible to think of the FlexStylus as providing this kind of continuous bipolar input, with the addition of another continuous parameter that modifies the first, the device angle. While these two types of supplementary input are useful for "regular" augmentation of x-y input (in the manner of the pressure sensor), we are also interested in using these analog values in more abstract ways.

With FlexStylus, the user can make use of the multiple kinds of analog inputs to create a selection of artistic tools which are nuanced and responsive to the movements of their hand. The most basic parameters connected to the flexible stylus are absolute flexion and bend angle. However, because the fibre optic sensors provide detailed analog measurements of the device's state, software can derive further parameters related to the user's artistic intent. For instance, the rate of bend change can control a different parameter from the absolute degree of bend. By expanding the number of parameters, taking into account rate as much as absolute bend, we aim to create a feeling of richness and depth, as well as embodiment.

In addition, the stylus's capacity to detect both flexion and rotation allows the bend state of the FlexStylus to function as a kind of secondary pointer, which the user can manipulate by planting the tip of the pen and deforming the stylus. Altering of the bend state in this way makes use of similar hand motions to moving the tip of a rigid stylus, which enables the user to quickly send gestural commands to perform selection tasks, but without the necessity of moving the stylus' tip.

Hardware Implementation

Because the stylus was designed to detect directional flex input, it was important to devise a sensing system that did not have the limitations of conventional thin-film bend sensing. Using a thin-film (i.e. flat) sensor, it is only possible to detect bend along one axis. To create a device which could be flexed in any direction, the flexible stylus employs a cluster of fibre optic flexion sensors, in a similar approach to the Twend prototype [7] and ShapeTape [4]. The FlexStylus prototype employs four directional fiber optic sensors which respond asymmetrically to flexion input (Figure 3). By combining the output of the four sensors, we derive both an absolute measure of the flexion of the device and a measure of the angle at which it is being flexed.

Each of the four flexion detection fibres is abraded on one side using a blade until the abraded section measures 1 mm in width. The abraded sections are angled at 90° to one another. As the device is flexed, infrared (IR) light escapes from the abraded sections. The amount varies depending on the direction and amplitude of flex: a significant amount of light escapes the fibre only when it is bent in the direction opposite to the abraded section. Kuang et al. [9] provide a detailed explanation and evaluation of a similar bend sensing technique.

The prototype uses four surface-mount IR phototransistor devices. Each one measures the luminescent output at the end of one 1.5mm diameter plastic fiber optic cable. The tip contains a single 5 mm IR (λ = 940 nm) LED. The rigid pieces coupling the LED to the fibres, and the fibres to the phototransistors, are 3D printed and made of PLA plastic.

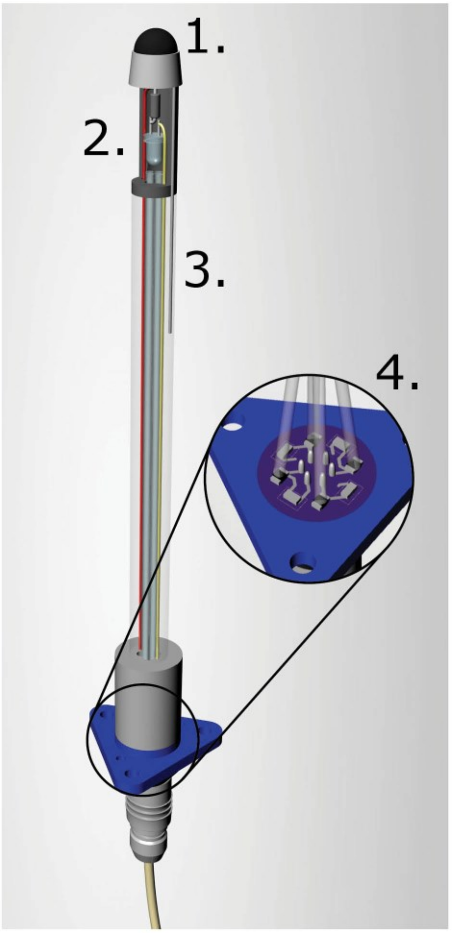

Figure 3: A rendering of the FlexStylus prototype, showing: 1. Capacitive tip, 2. IR LED (Cutaway), 3. Wire for transmitting hand capacitance, 4. Detail of circuit board with 4 phototransistors coupled to fibre optic sensors.

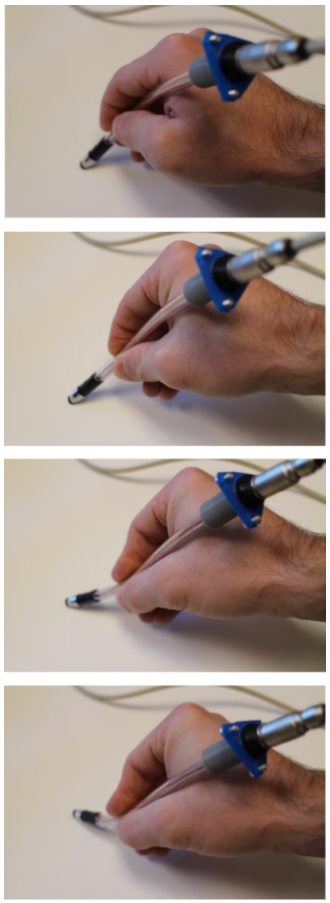

Figure 4: Four different angular bend configurations.

A conductive rubber nib from a commercial tablet stylus is affixed to the tip of the prototype, along with a small piece of wire running parallel to the device. This wire transmits the capacitive charge from the user's hand to the nib, enabling the FlexStylus to be used with conventional capacitive tablet screens.

The device is connected to a computer using an Arduino Uno [3] microprocessor. In software, the input of each bend sensor is mapped to a value between 0 and 1, with 1 representing the largest amount of deflection, and 0 representing an unbent sensor. Then, each perpendicular pair of sensors is treated as an axis on a Cartesian plane. By summing these inputs, we are left with a coordinate pair, and the rotational angle of deformation is determined by determining the angle of a line between this point and the origin. The amplitude of bend is calculated by simply determining the length of this vector. The drawing application is streamed wirelessly to a tablet screen. X-Y touch information is gathered from the tablet screen and combined with bend data in the drawing application.

Continuous Parametric Input

FlexStylus allows for a variety of interactions, from simple, unidimensional ones to complex interactions using multiple sources of input concurrently. Users are able to select which painting parameters can be mapped to which types of flex input, allowing them to create their own tools which suit the current artistic motivation.

In a simple use case, the flexible pen can be used in a manner similar to an augmented stylus, such as those commercially available styli that have pressure detection. The absolute bend of the stylus is correlated with the stroke width. As the artist becomes accustomed to the feel of the device, a greater number of effects can be simultaneously manipulated using the hand, while at the same time directing the stroke in the x-y axis. A more complicated use case might involve an artist who uses the absolute flexion to control the width of the stroke, while at the same time using the angle of deflection (Figure 4) to control the saturation or colour of the stroke.

Taking into account not only measurements of the current device state, but also rate of change in the analog values, results in a multiplication of artistic possibilities. This is particularly useful in abstract digital painting. For example, an artist, rather than reproducing a pen stroke, might use the bend function to create abstract and emotive brush effects, based not only on angle and degree of bend, but on the degree of liveliness with which they manipulate these parameters

Gestural Interaction Space

It is also possible to use the stylus to execute gestural commands without moving the tip of the device. The bend state of the device, like a vector, can be expressed in two different ways: either as a magnitude and an angle, or as a point in relation to the Cartesian origin. Each way of expressing the bend state can be associated with different kind of interactions. Conceptualizing bend input as a magnitude and angle is easily associated with the kind of interactions described by Ahmaniemi et al. [1]—continuous, bipolar bend gestures, with a neutral state. These kinds of interactions, like altering the size or colour of the brush, are most likely to take place simultaneously to drawing interactions, enabling the bend input to function as a kind of supplementary input, similar to pressure or tilt. The other way of conceptualizing bend interactions, as a Cartesian point, allows the creation of a new space of interactions involving an additional cursor that does not need to be collocated with the tip of the stylus. This allows users to seamlessly provide gestural input for command execution and mode switching without having to move the point of the stylus (Figure 5).

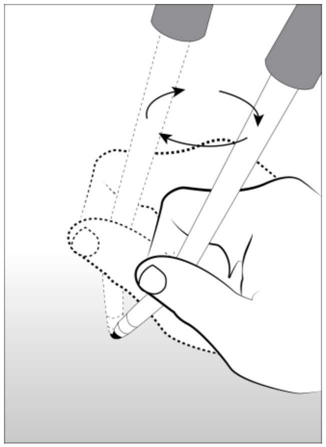

Figure 5: Demonstrating gestural commands with the FlexStylus. The user moves the body of the device in a circle without moving the tip, which is registered as a "circle" gesture.

Embodied Interactions for Expressionism

It is logical to attempt to devise an embodied interface to be amenable to predictability and easily reproducing user intent. HCI research is frequently structured around the notion that the physical mode of interface ought to represent the most efficient possible means of registering user intent. Since the goal of the flexible pen prototype is conveying artistic expression, we propose a device which thoughtfully undermines this philosophy. In the production of art, the physical limitations, idiosyncrasies, and contingencies of the medium are as much a part of the production of the art as the intent of the artist. By creating an interface device and means of interacting with the device that are largely predictable, but contain depths of behaviours more associated with these physical media, we bring into digital painting the embodied subtleness of movement more associated with traditional art practice.

Conclusion & Future Work

We have presented FlexStylus, a flexible stylus which uses 2 channels of analog bend input to give digital artists embodied tactile control over their work. The FlexStylus was implemented using an optical bend sensing technique; it differs from the majority of deformable devices in that it measures both absolute deflection and angle of deflection. Users can take advantage of this relatively large information bandwidth to simultaneously control multiple parameters while using the device to create art. We also propose a new kind of interaction technique which enables users to execute gestural commands using the bend state of the device without needing to move the stylus tip/drawing cursor.

Future work includes improvements to both the software and the hardware components of the device, as well as user studies. User studies will start by examining the system on a human-factors level, determining ideal bend angle ranges based on hand position and pen grip, as well as the degree to which the two bend inputs and x-y input are affected by one another during simultaneous parameter manipulation. Future work will also consist of examining applications for this input method in menu navigation, comparing it with already existing augmented stylus-based menu navigation systems. Planned enhancements of the prototype are largely cosmetic and pertain to durability, as well as using a custom molded body, to help users to easily orient the flexible stylus based on the feel the device in their hand. Future development on FlexStylus software will focus on integrating the hardware input into pre-existing paint software, enabling the system to be evaluated and used by artists outside of a limited prototype application.

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