Kinetic Skin: Feasibility and Implementation of Bare Skin Tracking of Hand and Body Joints for 3D User Interfaces

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Abstract

Kinetic Skin is a thin, adhesive patch that employs resistive sensing via a meandering carbon ink trace, where the circuit designs are printed on temporary tattoo material, similar to ones worn by children for decorative play. Each tattoo sensor is worn on your body across a joint (ie. finger, wrist, and elbow joints). In this paper, we present implementation details of prototyping Kinetic Skin worn on the finger and wrist joints for relative tracking to control 6-DoF manipulation. We demonstrate translation, rotation, and scale of virtual objects, including camera navigation. In this paper, we describe four interaction techniques that map finger joint input to 6-DOF control. The potential of this technology could be used for long-term light weight tracking of body movements to inform rehabilitation; for dance, music, or other performing arts; for gaming; and for other 3D User Interaction in Virtual and Augmented Reality Applications.

Index Terms: B.4.2 [Input/Output Devices]: ;— [I.3.1]: Hardware Architecture—Input DevicesThree-dimensional displays; H.5.2 [User Interfaces]: Interaction styles—

1 Introduction and Motivation

Interaction in Virtual and Augmented Reality applications often benefit from one-handed or two-handed interaction, gesture-based input, virtual object manipulation, and navigation [3], yet hand and gesture tracking remain one of many challenges that still exist for 3D User Interface (3DUI) applications [22]. There are multiple solutions for joint tracking. External cameras, that are fixed either in the world [26] or on a user [27], can be used to track Fiducial markers on the hands [32] or bare hands [6, 12]. Typical challenges with these camera-based solutions include time consuming calibration, occlusion (of the joints as they are flexing), limited scope of large scale or outdoor capabilities, and expensive equipment. Another solution that enables hand tracking is a set of gloves with bend sensors [10, 21], however also involves time consuming calibration and can be too loose or too tight on a user's hand.

Kinetic Skin (Figures 1 and 2) is a technique extended from the methodology of Sensing Kirigami [31], which was in turn inspired by Flexy [25]. In these interfaces, colleagues explored the use of printing conductive ink on paper surfaces and using carbon-coated paper for actuating paper. For Kinectic Skin, the input designs typically printed on paper are instead printed or fabricated as a temporary water based tattoo. Each tattoo sensor is worn on your body across a joint (for example but not limited to: finger, wrist, and elbow joints). In this paper, we present the feasibility and exploration of parameters for Kinetic Skin. We also prototype and demonstrate the usage of Kinetic Skin for two-handed (fingers and wrist) as a 3D User Interface. Finally, we describe a least four interaction technique designs for finger and gesture tracking in an Virtual, Augmented, or Mixed Reality Environment.

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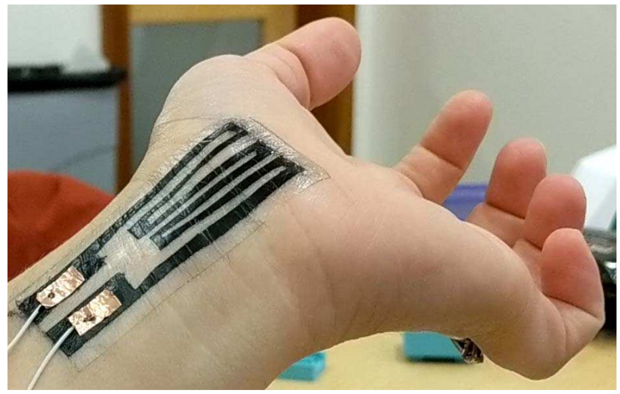

Figure 1: An example Kinetic Skin adhesive patch placed perpendicularly across a wrist joint for tracking flexion and extension.

Figure 2: An example of the folds made in a Kinetic Skin adhesive patch when a wrist joint is flexed.

2 Related Work

Full body tracking is capable with multiple solutions of wearable wireless sensors [13, 17, 20] and previous researchers have developed low cost devices for individual finger tracking [15] but inertial tracking can cause drift error, where our solution will not have drift error. Other hand or gesture tracking perform well without drift error, however require the use of cameras or computer vision [6, 12, 30] or other low-cost electronics for hand tracking [16]. Kinetic Skin does not require the need for external cameras and computer vision processing techniques. This enables the user to track the fingers in configurations, such as complex gestures, that may be more difficult

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to track using cameras due to occlusion when the fingers are flexed. Gloves with flex-sensors have been developed for hand and finger tracking [1, 11, 33], however using a glove may require multiple versions available for exact fitting or may be too loose to track subtle movements of the fingers. Kinetic Skin will detect very subtle movements in joint movement, such as a tiny finger flex (Figure 7). However, further testing is needed to reveal exactly how precise the input is. A low-cost glove have been developed using a conductive polymer (PEDOT:PSS) thin film printed on glossy photo paper. This glove has been demonstrated to conduct real-time hand tracking [18, 24].

Other skin-worn adhesive tracking technologies exist and could be used for tracking, however none that provide or have demonstrated usage for 3D tracking input. Springlets are expressive, non-vibrating mechanotactile interfaces on the skin, embedded with shape memory alloy springs [7]. Springlets have six tactile primitives: pinching, directional stretching, pressing, pulling, dragging, and expanding. Tacttoo is a wearable, thin-skin adhesive embedded with sensors that allow you to feel tactile elements from an interface [29].

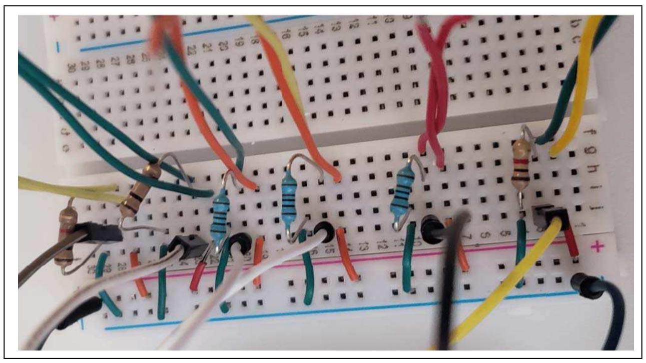

Figure 3: Our preliminary prototype uses an Arduino for power and a breadboard per hand with six resistors to route power and data through each Kinetic Skin adhesive patch to track six joints per hand.

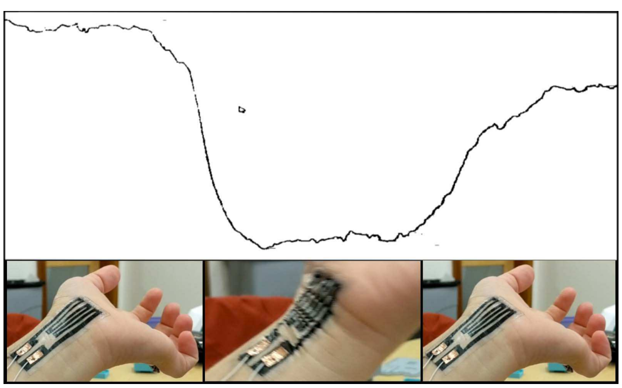

Figure 4: Sample variable input plot from a Kinetic Skin patch on a wrist joint revealing a unique signal during Flexion/Extension.

3 Kinetic Skin Prototype

Kinetic Skin employs resistive sensing via a meandering carbon ink trace. The electrical resistance of the carbon trace decreases as it is compressed, and increases as it is stretched. This change in resistance can be measured with a voltage divider circuit. As mentioned earlier, the method fabricating Kinetic Skin is extending from the method described in Sensing Kirigami [31]. We used conductive ink (ie. Bare Conductive conductive ink) to stencil a circuit design onto temporary tattoo material (Figure 1). In this case, we have printed the design of Kinetic Skin on water-permeable paper. Applying the temporary tattoo on a user's skin involves using water to dissolve the adhesive of the ink component with the paper component.

As such, in the fabrication of Kinetic Skin, we had to add a thin protective waterproof layer over the conductive ink between the paper and the ink. We experimented with various types of clear glue to create this protective layer. Although we use non-toxic glue, this layer or portion of the Kinetic Skin does not come in contact with the skin- it simply protects the conductive ink from running, since it is water soluble, due to the moisture exposure in the application process. This in turn protects the skin from conductive ink running on the skin. Due to this layer, we had to attach the wire leads to the Kinetic Skin element before adding these additional layers. The other side of the Kinetic Skin is made of the adhesive layer from the temporary tattoo material, which is the layer that comes in contact with the skin. The materials differ among manufacturers but we select one that is in compliance with US FDA regulations. An added layer of silicone could protect the skin and is considered both hypoallergenic and non-comedogenic and not known to sensitize the skin. The silicone layer needs to be very thin, so it is best to cure it on a flat surface (instead of a mold) and spread thinly with a flat knife to cure a paper thin layer (ie. film layer is 20 µm (0.0008")). The thinner the combined layers, the lighter it is and the more natural joint mobility it will permit. The silicone layer can be applied directly to the temporary tattoo material.

To power the Kinetic Skin and process the input to an application, our current prototype uses an Ardiuno board connected to a PC running Unity and Artidy [28], first developed for [9]. Provided a voltage the total current that runs through the Kinetic Skin will determine the range of input. As the joint is bent, the voltage decreases. As the joint opens again, the voltage increases. Using this variable input (Figure 4), a single binary operation could be mapped or a variable operation, such as translation, rotation, or scale, could be mapped. In our current prototype, we integrate resistors attached to the arduino on a breadboard (Figure 3). However, with inspiration from Sensing Kirigami [31] we are currently experimenting with the resistor integrated into the Kinetic Skin design as well as simplifying the power source to battery operated and sending input data wirelessly. We experimented with size of the design as well as simplicity of the design. Our first prototype follows a hinge design schematic [31] and we further simplify it as shown in the right of Figure 5. In our initial prototype, we offloaded the resistor onto a breadboard. However, the Sensing Kirigami schematic includes a resistor in the circuit design. For larger joints, such as the wrist, including the resistor may not have interference given the flat forearm below. However, to include a resistor in a Kinetic Skin for smaller joints (ie. finger joint), the resistor may need to

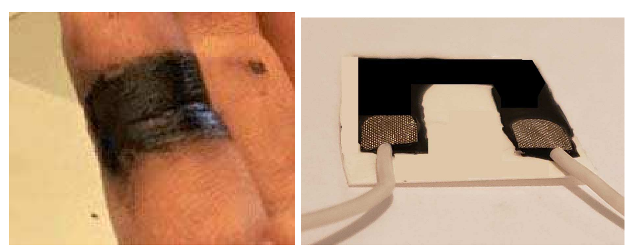

Figure 5: Simplified Kinetic Skin, improved for finger joints. A single path (left) parallel across a flexion crease provides noisier input. To provide a clean input signal during Flexion/Extension, there needs to be at least two paths (right) perpendicular across the flexion crease.

be designed such that it aligns with the side or back of the finger (Figure 6), so movement of other finger joints do not interfere with the circuit, causing a false positive or negative result. We found that more intricate the design, the more reliable and higher resolution the signal was. The simpler design also allowed for accurate detection of a joint flexion/extension, but the range for that angle was more constrained (Figure 5, right). Initially we might recommend smaller more simple versions for finger joint data sensing and more complex larger versions for larger wrist and shoulder joint sensing. Furthermore, the wrist and shoulder joints are more complex and with initial testing, we were getting false-positives depending which angle the joint was flexing. Initially, we might recommend adding two, one for each side the joint moves, but further testing is needed. These are initial findings from testing a small sample of fabricated Kinetic Skin elements.

These initial results will inform the hypotheses for our future controlled experimental user study to more adequately determine how these parameters (circuit complexity and size) affect the performance for various joint types. Furthermore, there is the potential to develop a learning tool that can suggest optimal Kinetic Skin sensor placements and circuit designs based on a set of interactions to be detected, similar to [23]. With such a tool, we might be able to identify a set of base parameters and flexible ranges to enable more creative expression for the design of the meandering trace, similar to henna body art [4].

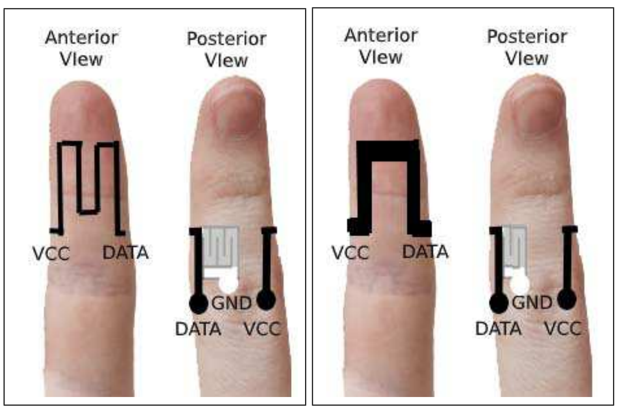

Figure 6: A schematic for an improved Kinetic Skin adhesive patch including a resistor in the design. This is adapted from a hinge schematic in [31] for use on a finger joint. The left shows a more complex circuit and the right shows a simplified one as in Figure 5.

4 Interaction Modalities that Use Kinetic Skin

We demonstrate the usage of Kinetic Skin for a 3D User Interface. We explored the use of finger and wrist controls for 6-Degrees of Freedom manipulation. We present four mappings among the finger joints. These mappings are extended from those mappings evaluated in a previous study [8]. Please refer to Figure 8 for clarification of finger joint location and Figure 7 for movement. In the future, we will conduct an experimental study to investigate the performance provided by these mappings.

3DOF Continuous-Flex For the first mapping,Continuous-3DOF, we divided the labor among two hands, assigning 3-DOF translation to one hand and 3-DOF rotation to the other. Change in translation or rotation along each access is represented by one finger joint assigned to each axes. When each finger flexes then the value continuously changes in the negative direction while extends the finger continuously changes the value in the positive direction. When the finger straightens, the change stops. The scale is controlled by flexing/extending the wrist joints. Similarly we could map these

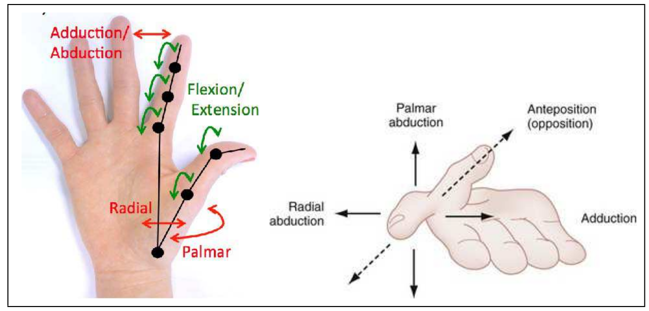

Figure 7: (left) A diagram of directional movement for each finger joint [2] and (right) added illustration of thumb movement [14].

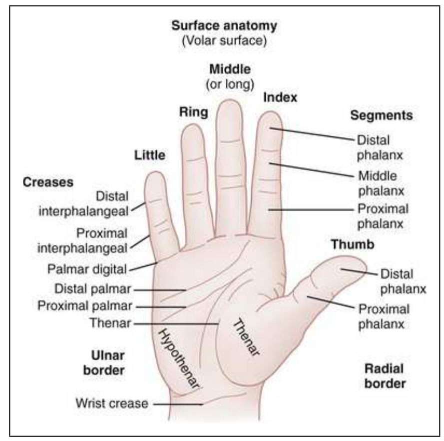

Figure 8: A diagram identifying finger joints [5, 14, 19].

controls to the Adduction/Abduction movement (Figure 7) of the joints, 3DOF Continuous-Adduct.

3DOF Clutch-Flex In the second mapping, Clutch-3DOF, instead of continues input value change, we use a form of clutch mapping. Each time a finger flexes, then extends, and flexes again- the value of the object that is being manipulated moves by a variable amount (indicated by the amount of flex/bend) along the corresponding axis to that finger, then from that new position/rotation it moves by the next variable amount. In this case we need to assign positive and negative axial controls to separate fingers. That means for 3-DOF on one hand we need to use 6 joints. Fingers close in proximety will handle positive-negative control. For example, the ring finger and the pinky finger will handle positive-negative control, respectively, for the x-axis. The index finger and the middle finger will handle positive-negative control, respectively, for the y-axis. The thumb Interphalangeal (upper) joint and the thumb Metacarpophalangeal joint (where it meets the palm) as a result of Palmer movement (Figure 8) will handle positive-negative control, respectively, for the z-axis. Similarly we could map these controls to the Adduction/Abduction movement of the joints, 3DOF Clutch-Adduct.

3DOF Double-Joint-Clutch-Flex Another variation of Double-Joint-Clutch-3DOF is use two joints from each finger, totalling three fingers. When flexing the Distal (top) joint, the value along the positive direction of the corresponding axis changes. When flexing the Middle joint, the value along the negative direction changes. In this mapping, we are not using the proximal joint. In this case, we must disable positive control when the bottom joint is flexing because naturally the top joint flexes to be able to flex the bottom joint. Similarly we could map these controls to the Adduction/Abduction movement

(Figure 8) of the joints, 3DOF Double-Joint-Clutch-Adduct.

3DOF Mixed-Joint-Motion In 3DOF Mixed-Joint-Motion, we can map control onto the different types of joint movement between Adduction/Abduction and Flexion/Extension (Figure 8). Adduction/Abduction of the joints can be assigned to control along the y-axis, Flexion/Extension can be assigned to control along the z-axis, and Radial/Palmar of the thumb to control along the x-axis. In this case, all fingers move together rather than separating out individual finger control, so as to reduce cognitive fatigue.

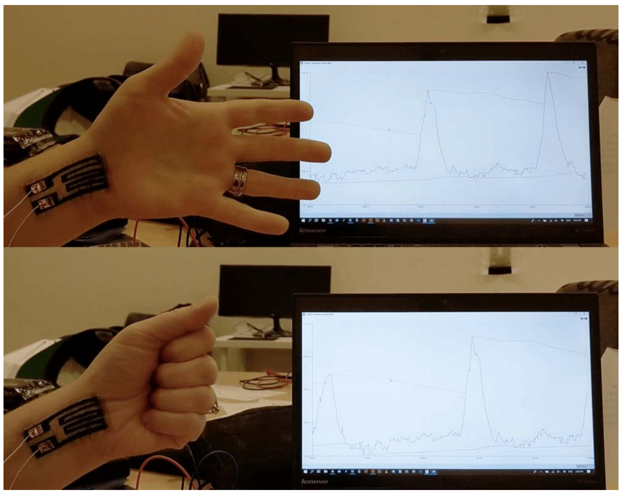

Figure 9: Example unique gesture recognition of open/closed fist using a single Kinetic Skin adhesive patch on the wrist.

5 Summary and Future Work

In this paper, we presented Kinetic Skin, a novel thin electronic adhesive patch sensor that has the potential to be used for body joint tracking. We presented the exploration of design, size, complexity, and joint placement for variable input data. In the future, we will conduct a controlled experimental study to further understand the properties and performance benefits of Kinetic Skin. We also demonstrated the usage of Kinetic Skin for two-handed (fingers and wrist) as a 3D User Interface. We discussed our prototype system and finger joint mappings for 6-DoF manipulation control in a 3DUI. These can then be combined with one or more absolute tracking techniques for more precise full body tracking. We described four interaction designs to divide the labor of 6-DoF manipulation of virtual objects from the joint input. These mappings were designed to consider ergonomic handedness control. For example, we maintained similar movements across the joints of the middle, ring, and pinky fingers when they move together. From these mappings, we will conduct an experimental user study to investigate which techniques provide better performance, are more preferred, and have ergonomic control. Beyond individual finger tracking, through preliminary testing, we also found that Kinetic Skin has the potential to detect gestures formed by a combination of finger movement (Figure 9). In summary, Kinetic Skin has the potential to provide a cameraless gesture tracking for 3D User Interfaces in circumstances when certain gesture configurations may be occluded from the camera or 6-DOF manipulation and navigation control providing full range of motion when other methods may hinder joint movement.

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