Nail+: Sensing the Strains From Fingernail As Always-Available Input

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ABSTRACT

We present Nail+, a nail augmented device that senses user's fingernail contour and bend when force is applied on a surface. Using 3×3 array of 0.2-mm strain gauges, Nail+ is small enough to fit on fingernails, and at the same time, flexible and stretchable. We evaluate this interface in motion and motionless mode. The system can distinguish swipe gestures with high accuracy (93.2%). For motionless mode, it can achieve 85.6% accuracy for classifying different kinds of finger postures. Since the device is always available, it allows users to perform swipe gestures on surfaces around or touch postures on touch screen devices to enable a variation of application usage. We also show some example scenarios of using this technique such as smart TV and smart watches for extending input area and dimension.

Author Keywords

Natural User Interface (NUI); Wearable electronics; fingernail; Strain gauges; Machine Learning; Nail pressure;

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Input devices and strategies (e.g., mouse, touchscreen)

INTRODUCTION

Recent works have seen new proposals for nail augmented devices in body-attached computing. Fingernails have been widely adopted due to its characteristic of lacking perception, being non-obstructive and the most promising place for easy installation and removal[9]. Moreover, nail art has been proposed in previous works[12, 10]. We believe that using nail as a mounting location will become more popular in the future.

Prior works on fingernail mounted devices develop schemes to augment fingernails as an output of display and a signal source for sensors. NailDisplay[12] mounts a visual display on top of fingernail to show the content underneath the fingertip. Ando et al.[1] proposes to put a small voice coil to control the tactile feedback from surface by changing waveforms. More than that, FingerSight[5] implements a device consisting of a camera to extract environmental information. Previous research also demonstrates using nail-mounted device to enrich input area. NailO[10] proposes a capacitive sensor grid on top of the fingernail to sense swipe and tap gestures. uTrack[4] and FingerPad[2] places small magnet on the fingertip, and uses a magnetic field to track finger movements. TouchSense[7] uses 3-axis accelerometer to detect finger postures for switching different modes of input. These works have proven the advantages of a device mounted on top of fingernails, yet have not explored the characteristics of a fingernail itself as a signal source.

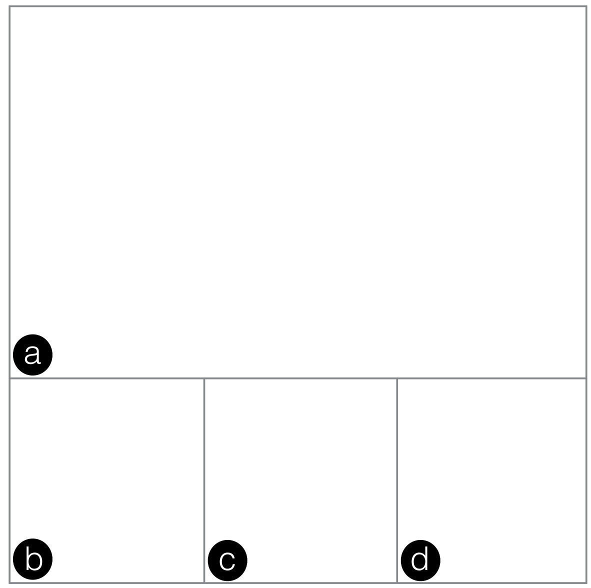

Figure 1: Nail+ THIS IS A PLACE HOLDER FOR Nail+

This brings us to think about using a fingernail as an input property proposed in [8], which senses force touch via computer vision. Mascaro et al.[11] also implements a nail-mounted device for observing changes in the reflection intensity on a fingernail. However, these techniques still have not explored the movements sensing which leaves in question the recognition of swiping gestures.

In order to explore better sensing technique of nail augmentation, we aim to design a device that achieved the following designs. First, it has the ability of sensing simple gestures (e.g. swiping and tapping) on surfaces. Secondly, it has no restrictions on input area which enable users to perform gestures on surfaces around. Finally, it should come in a light

Every submission will be assigned their own unique DOI string to be included here.

and thin form factor to preserve the unobtrusiveness of fingernails. The proposed design will be a novel input device for increasing the mobility of touch screen. It also can be performed gestures anywhere without physical effort.

In this paper, we developed a prototype, Nail+ (Figure 1), utilizing a 3×3 array of strain gauges sensor to explore the technique of using strains from fingernail as input.

In summary, the main contributions of this paper are as follows:

- A novel fingernail input interface presented and explores the ability of fingernail's strains as a input technique.
- We develop a nail-mounted prototype can detect swipe gestures and finger postures.
- We conducted two system evaluations of this technique and implemented scenarios to explore interactions.

PROTOTYPE DESIGN

Few main design requirements were needed. First of all, the device must be small enough to fit within fingernail. Second, it should have ability of sensing slightly changes of the strain from fingernail. Last but not least, it has to be reusable and easy for installation and removing. Thus, we derived that using a 2D array of 0.2mm strain gauges is the proper solution for this prototype. To derive a general fitting, we conducted a pilot study to collect the average size of fingernail.

Pilot Study : Size of Fingernail and Human Behaviour

We recruited 10 participants (7 male, 3 female) from ages 20 and 24 (mean 21) to find an average width and height of fingernail. We also requested users to perform tap gesture on electronic load-cell to measure how much pressure is applied on a surface to investigate the ability of strain gauges. The pilot study showed, fingernail width is 1.145cm (SD=0.14) and height is 1.21cm (SD=0.17). And the average of tap pressure measured 0.82N (SD=0.26).

Hardware

We developed Nail+ using a 3×3 array of 120-ohm 0.2-mm strain gauges for sensing part (Shown in Figure 1). Below the strain gauges, we used a stretchable and flexible artificial-skin to adhere sensors onto user's fingernail. The size of it only takes 0.9cm×1cm which is smaller than 1 US cent, and the thickness of it is 1mm. Each of the strain gauge is directly wired to the computing part. The computing hardware is consisted of an Arduino Nano board and two 8-to-1 analog switches(MAX4617, Maxim Integrated), a dual digital potentiometer (AD5231, Analog Devices), and two instrumentation amplifiers (AD623, Analog Devices and INA122U, Texas Instruments).

The diagram of the computing hardware is shown in Figure 2. First, the multiplexers are sequentially selected to connect one of the strain gauges. Upon gauge selection, it becomes one of the four resistors on the Wheatstone bridge. When the forces apply on fingertip, the strain of fingernail causes slight bend or contour which causes the ohm value to be lower or higher. Due to the changes of ohm value, one side of the voltage in Wheatstone bridge also changed. This difference becomes our sensing signal input.

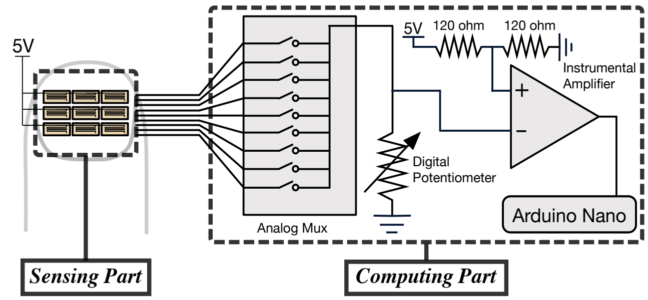

Figure 2: The complete circuit diagram. Sensing part is consisted with 9 strain gauges. For computing part, we actually used two analog multiplexers and the instrumental amplifier is made up of two amplifiers as well.

Due to changes to strain being slight, we used two amplifiers to magnify the difference on both sides of Wheatstone bridge 4000 times. Finally, Arduino Nano reads the final analog value from the last amplifier's output. The digital potentiometer is used for adjusting the resistance to let the Wheatstone bridge have no difference on both side during calibration.

Gesture / Posture Recognition

We used LIBSVM tool[3], a popular machine learning open-source library for SVM which is a way to distinguish the pattern by vectors. Since the different type of the input data sets, we implemented two algorithm specifically for swipe gestures (Motion mode) and finger posture (Motionless mode). In motion mode, sequential and time based data is preprocessed by accumulating each data's difference from the first received data when the gesture began. At the end, the sequentially data is processed to be one feature data. In motionless mode, raw data is directly used for machine learning. For each mode, we scale data's feature to the range of -1 to 1 and then train a multi-class SVM classifier with a Radial Basis Function (RBF) kernel.

SYSTEM EVALUATION

The goal of the evaluation is to explore: (1) Capability of classifying different kinds of swipe gestures when user perform gesture on surface. (2) Finger posture angles can be identified at user daily usage pressure level. (3) Sensing a force touch.

Participants

We recruited 10 participants (7 male, 3 female) between the ages of 20 and 23(mean 21.3). All participants are right-handed and drew with their right index fingers on the surface. Each participants received $5 after one hour experiment.

Apparatus

We used the same load-cell sensor (Error: ±0.5 grams) as our pilot study. In this experiment, we instrumented a 9 degree of freedom (9DOF) sensor on user's index finger. Since the strain gauges are very sensitive to the strain, we avoid 9DOF sensor to contact fingernail. The 9DOF sensor is only used for checking whether user is performing the applicable position

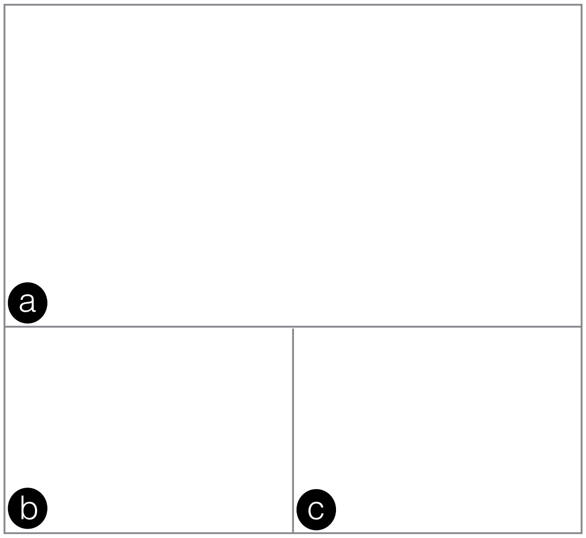

Figure 3: The apparatus in our user study. At the surface, we put a load-cell sensor below (b). For each user, we put a 9DOF (c) sensor on finger and our Nail+ device on fingernail.

and angle for collecting data. The surface we used consists of medium density fibreboard.

Task and Procedure

Motion Mode

We chose four swipe direction (up, down, left, right) and tap for this study. Users were requested to perform gestures shown on computer screen in front. On the desk, we drew instructions of swiping to ensure swipe direction and distance is consistent. Each direction is randomly selected to show on screen, and collected with 10 sets of sequential data which contains a total of 80 trials for each user. A calibration is needed for the first time wearing but no further calibration was needed.

Motionless Mode

In this mode, we tried a variety of finger postures with different pressure levels. For each trail, the participants were instructed to adjust their finger pitch and roll angle which are partially selected from [6]. We only chose the angles which are easily identifiable, and gesture set is shown in Figure 4. The forces are chosen from our pilot user study: average force (0.8N), one SD forces (0.6N, 1.0N), two SD forces (0.4N, 1.2N). The participants were asked to straighten their finger during the entire experiment. In front of the user, there is a screen showing current (sensing from 9DOF and load-cell sensor) and instructed angle and force. Before each trail, participants were required to return the initial position. When participants adjusted their finger to the correct posture and performed the correct pressure (tolerance: ±5grams), we start to collect data. Once posture or pressure is inapplicable during the study, recorder will automatically skip the data. For each user, we collected 5 postures with 5 forces for 5 times, which is total 125 trials.

Results

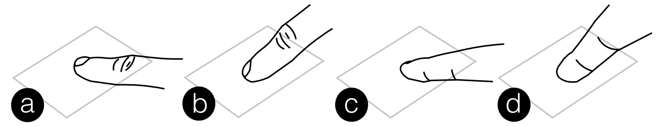

Figure 4: Motionless posture sets: (a) pitch 15 degree, (b) pitch 45 degree, (c) pitch 15 degree and roll 45 degree, (d) pitch 45 degree and roll 45 degree

Motion Mode

The result of this study is shown in Figure 5. Off-line accuracy was computed using 10-fold cross-validation of the evaluation data. The mean accuracy across all participants is 93.2%(SD: ±5.98%). Most of the error occurred in swiping down and up, likely due to the higher friction caused user performed gestures lightly from surface which caused strain on fingernail does not observable for sensor.

Motionless Mode

The accuracy due to chance was 20%. Off-line accuracy was computed using 5-fold cross-validation of the evaluation data. The mean accuracy for mixed all force data together across all participants was 76.9% (SD: ±13.17%). The confusing matrix for each force level is shown in Figure 6, which shows that the higher pressure level the better accuracy gets. If we drop 0.4N and 0.6N data, accuracy can reach 82.44% (SD: ±12.74%). Note that most of the error happened in the angle of pitch 45 degree with roll 45 degree. We think it is due to the user sometimes performing postures directly with fingernail instead of fingertip when the roll angle is higher. This caused strain gauges to have different values for each trail which raises this error classification. For sensing force touch, we used 5-fold cross-validation to evaluate. However,

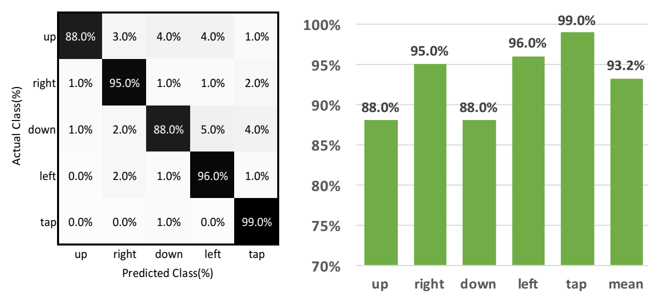

Figure 5: Motion mode: Confusing Matrix and Accuracy for four direction swiping and tapping.

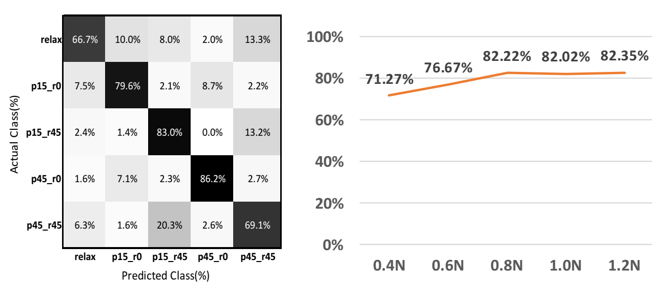

Figure 6: Motionless mode: Mixed-force confusing Matrix and Accuracy for each level of pressure.

it shows that it can only distinguish 0.4N and 1.2N pressure with 70% (SD: ±12.74%) accuracy.

EXAMPLE APPLICATION

Based on the advantage of Nail+, we show two examples using this new interaction technique and are included in video.

Controlling Smart TV / Devices

Smart TV's require us to take out the remote for controlling. With Nail+, user can focus on the TV program without the effort of taking out a remote. User can use couch as input surface to perform simple tap and swipe gestures for switching channels and selection. Furthermore, we also implement this on smart watch. Due to the smaller screen, it is handy to use swipe gestures on the surface as an interaction method.

Short cuts within application

For touchscreen, most of the devices can only distinguish binary state of touch. Using Nail+, user can use different finger posture to enable shortcuts such as right clicking on computer. For instance, the file system on smart phone can be controlled with 45 degree of roll angle to show a drop-down list to delete, move, and change the file name.

LIMITATION AND FUTURE WORK

Firmly sticker on fingernail: In our evaluation of system, we noticed that the artificial-skin became not sticky enough through time and many times of usage. This caused the misclassifications in this situation due to sensing part becoming separated. We will continue to find another option for device fixation.

Minimize computing part and Power consumption: As shown in Figure 1, we currently put the computing part on the wrist as a wristband form factor. The form factor is limited to Arduino Nano board size. This motives us to minimize the computing part into a ring form factor in future work. For the power consumption, we currently use 120-ohm strain gauges which can be replaced by much higher ohm gauges.

Sensing from all fingers: Mounting the device on all our fingernails is also our future work. Since more fingers are evolved, we can enable more functions such as multi-touch input like pinch and zoom.

CONCLUSION

In this paper, we evaluated using strains from fingernail as a input technique. We developed a nail-mounted device called Nail+, which is light and small enough to fit on top of fingernails. Evaluation of the this shows that it can distinguish swipe gestures on surface in high accuracy (93.2%). Not only for swiping but also the finger postures can identify five different kinds of finger posture at average force level with 82.22% accuracy. The system is also attractive for a nail-mounted always-available input for surface around which enrich the mobility of touchscreen. We also implemented applications for this technique, including remote controlling smart TV and watches and enabling short cuts on touchscreen device. Our currently plans are to extend this system to all fingers input.

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