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 0.2mm 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 applications such as quick swiping on surfaces around to control smart TV's or touching on touchscreen devices to enable different application short cuts.

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. It also has the advantage of being non-obstructive and the most promising place for easy installation and removal[9]. Moreover, nail art have been proposed in previous works[12, 10]. We believe that using nail as a mounting location will become more popular in the future.

Early 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 avoid the big thumb problem on touchscreen. 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. However, these works have not explored the characteristics of a fingernail itself as a signal source.

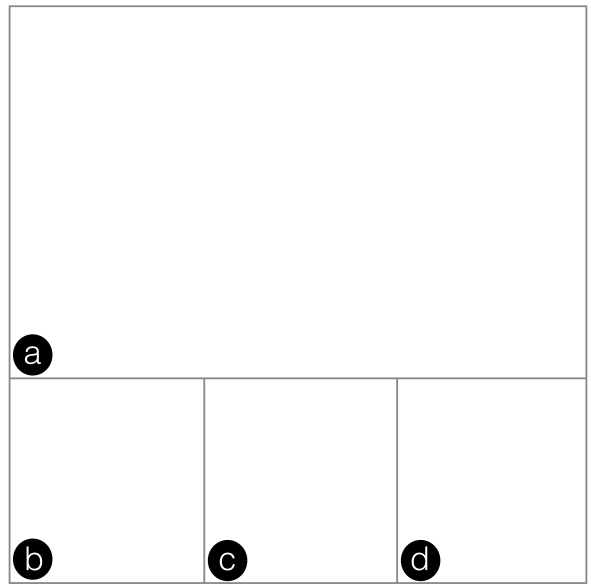

Figure 1: Nail+ THIS IS A PLACE HOLDER FOR Nail+

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. (one more work!) However, the sensing technique still leaves in question the recognition of swiping gestures and is limited to force sensing which is not enough for daily use.

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 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 perform 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 postures of fingernail.
- We conducted two system evaluations of this technique and implemented scenarios to explore interactions.

PROTOTYPE DESIGN

To design a nail augmented device for touch or gesture sensing, few main requirements were met. 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. Based on above of requirements, we derived that using a 2D array of 0.2mm strain gauges is the appropriate 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 normally applied on a surface to investigate the ability of strain gauges. The result of this pilot study, 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 instrumental amplifiers (AD623 and INA122U, Analog Devices).

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 one of the strain sensors is

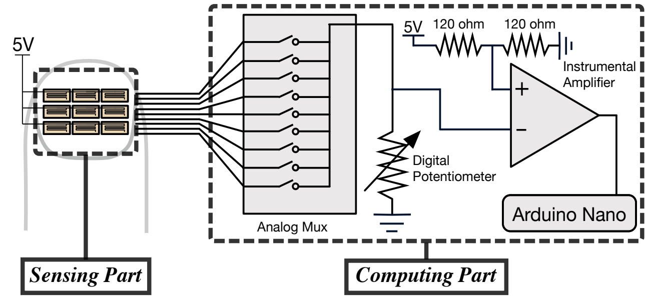

Figure 2: The complete circuit diagram. Sensing part is consisted with 9 strain gauges. For computing part, we actually used two analog multiplexers and the instrumental amplifier is made up of two amplifiers as well.

selected, it becomes one of the four resistors on the Wheatstone bridge. When the forces apply on fingertip, the strain of fingernail let the sensor slight bend or contour which causes the ohm value of strain gauges 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.

Due to the requirement of sensing the slightly change of the strain from fingernail, we used two amplifiers to magnify the difference on the two sides of Wheatstone bridge 4000 times. Finally, Arduino Nano reads the final analog value from the last amplifier's output. For the digital potentiometer, it 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, sequentially 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 study is to explore: (1) The system is capable for 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) The device is able to sense 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.

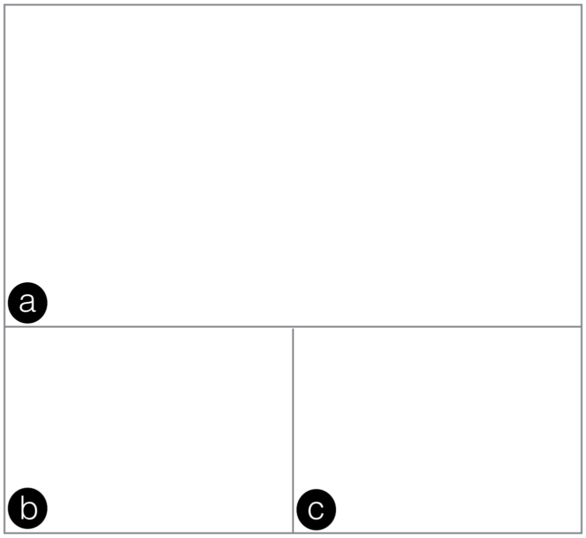

Figure 3: The apparatus in our user study. At the surface, we put a load-cell sensor below (b). For each user, we put a 9DOF (c) sensor on finger and our Nail+ device on fingernail.

Apparatus

We used the load-cell (Error: ±0.5 grams) which is the same in our previous 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. And the 9DOF sensor is only used for checking whether user is performing the applicable position and angle for collecting data. The surface we used in our study is 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 and press space key on keyboard at the beginning and at the end of the gesture. On the desk, we draw instructions of swiping to insure swipe direction and distance is the same for users. Each direction are randomly selected to show on screen, and collected with 10 sets of sequentially data which has total 80 trials for each user. Before the study, a calibration is needed for the first time wearing, and no calibration within this study.

Motionless Mode

In this mode, we tried to varies 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 easy to identify by users, and gesture set is shown in Figure 4. The forces are chosen from our pilot user study, following as average force (0.8N), one SD forces (0.6N, 1.0N), two SD forces (0.4N, 1.2N). The participants were asked to straighten finger during all experiment. In front of the user, there is also a screen showing current (sensing from 9DOF and load-cell sensor) and instructed angle and force. Before

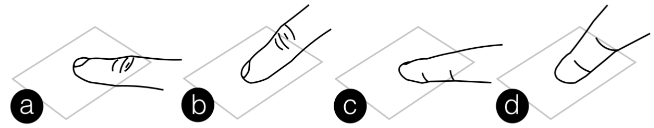

Figure 4: Motionless posture sets: (a) pitch 15 degree, (b) pitch 45 degree, (c) pitch 15 degree and roll 45 degree, (d) pitch 45 degree and roll 45 degree

each trail, participants were requested to return the initial position. When participants adjust finger to the correct posture and perform correct pressure (tolerance: ±5grams) on the surface, we start to collect data. Once posture or pressure is inapplicable during the study, recorder will automatically skip the data. For each user, we collect 5 postures with 5 forces for 5 times, which is total 125 trials.

Results

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 because 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

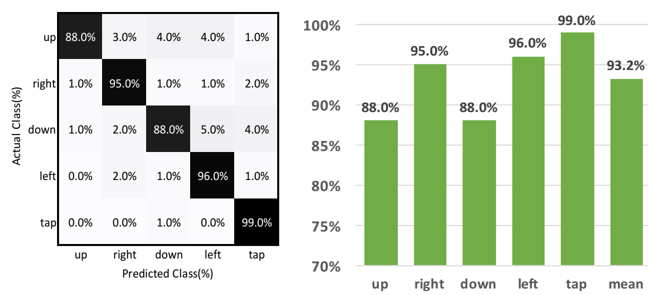

Figure 5: Motion mode: Confusing Matrix and Accuracy for four direction swiping and tapping.

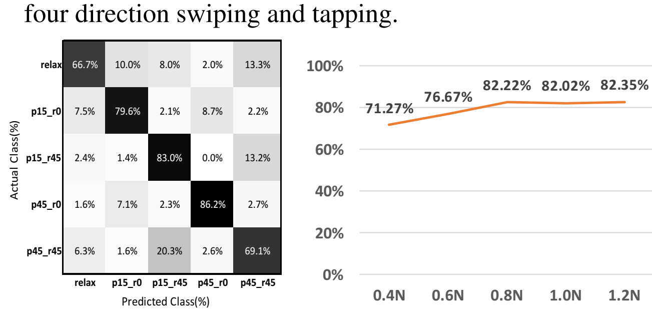

Figure 6: Motionless mode: Mixed-force confusing Matrix and Accuracy for each level of pressure.

that the higher pressure level the better accuracy gets. So if we drop 0.4N and 0.6N data, the 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 perform postures directly using fingernail instead of fingertip to touch the surface when the roll angle is higher. This caused strain gauges different value for each trail which raise this error classification. For sensing force touch, we used 5-fold cross-validation to evaluate. However, 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

In scenario of using smart TV, we always need to take out the remote for controlling. With Nail+, user can focus on the TV program without disturbing and physical effort for taking out remote. User can use couch as input surface to perform simply tap and swipe gestures for switching channels and selecting. More than this, we also implement this on smart watch. Due to small screen of the watch, it is very handy that using swipe gesture on surface as reply message or declining phone call.

Short cuts within application

For touchscreen, most of the devices only can distinguish binary state of touch. Using Nail+, user can use different finger posture for enable short cuts like right click on computer. For instance for the file system on smart phone, user can use 45 degree of roll angle to show up a short cut 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 passing and many times of usage. This caused the misclassifications in this situation due to sensing part separate from fingernail.

Minimise computing part and Power consumption: As shown in Figure 1, we currently put the computing part at wrist as a wristband form factor. The form factor is limited to Arduino Nano board size. This motives us to minimise the computing part such as 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 like 500-ohm.

Sensing from all fingers: Mounting the device all over our fingernail is also our future work. Since more finger evolved in this input technique, we can easily enable more functionality 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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