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 provide visual and tactile feedbacks. 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.

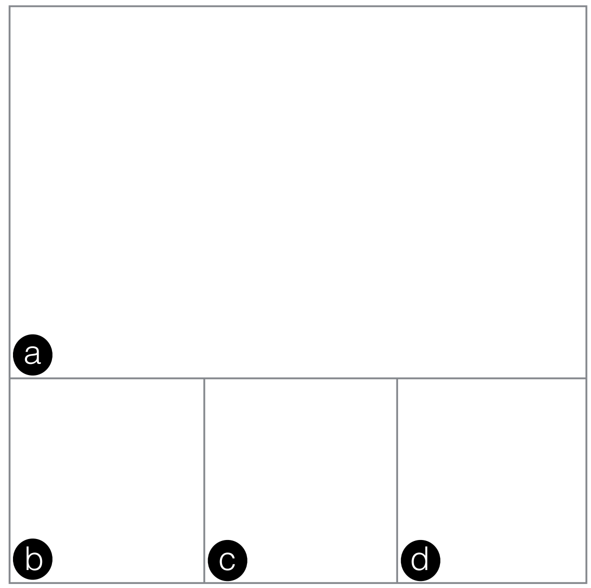

Figure 1: Nail+ enables using strains from fingernail as an input source. (a) The grid of strain sensors. (b) Computing part of Nail+. (c) Graph shows the strains result in different situations.

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 examined 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

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(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 performed gestures anywhere without physical effort.

In this paper, we developed a prototype, Nail+ (Figure 1), utilizing a grid of strain sensors 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 concluded that using a 2D array of 0.2mm strain gauges is the proper solution for this prototype. To derive a general fitting and daily usage pressure, 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). The average of tap pressure measured 0.82N (SD=0.26).

Hardware

Based on pilot study, 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

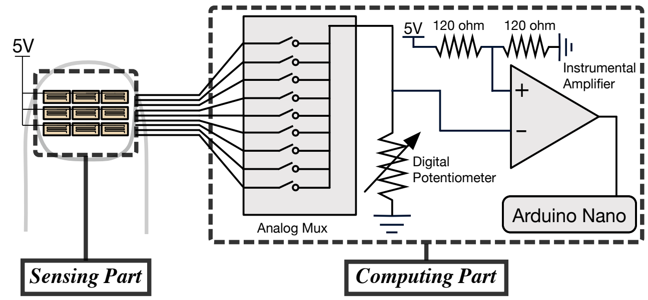

Figure 2: The complete circuit diagram. Sensing part is consisted with 9 strain gauges. For computing part, we actually used two analog multiplexers and the instrumental amplifier is made up of two amplifiers as well.

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.

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.

SYSTEM EVALUATION

In order to explore further interactions like movement gestures, we firstly wanted to exam the reproducibility of the strains of fingernail (Motionless mode). A further step, swiping gestures tested (Motion mode). The goals of the evaluation as followings : (1) The reproducibility from different finger postures at user daily usage pressure levels. (2) Capability of classifying different kinds of swipe gestures on surface.

Participants

We recruited 10 participants (6 male, 4 female) between the ages of 20 and 24 (mean 22.3). All participants are right-handed and drew with their right index fingers on the surface. Each participants received $5 after one hour experiment.

Apparatus

The apparatus is shown in Figure 3. 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 strain gauge is 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 and angle for collecting data. The surface we used consists of medium density fibreboard.

Task and Procedure

Motionless Mode

In this mode, we tried a variety of finger postures with different pressure levels. For each trail, the participants were

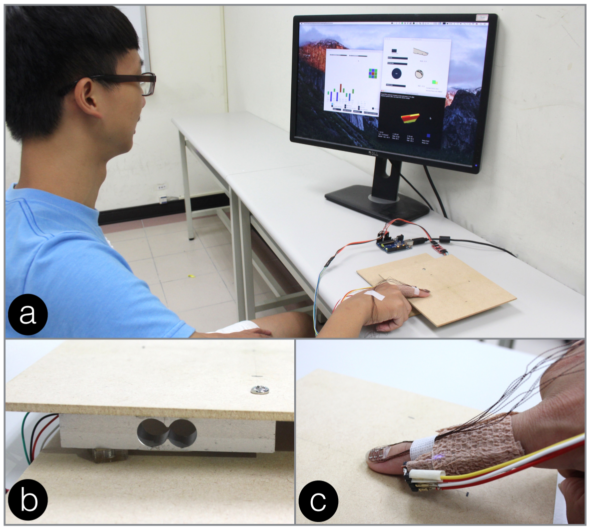

Figure 3: (a) The apparatus in our user study. (b) At the surface, we put a load-cell sensor below. (c) For each user, we put a 9DOF sensor on finger and our Nail+ device on top of fingernail.

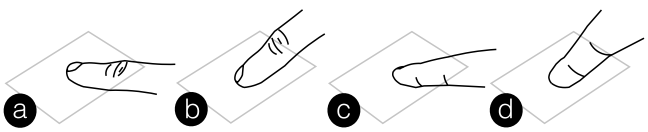

Figure 4: Motionless posture sets: (a) pitch 15 degrees, (b) pitch 45 degrees, (c) pitch 15 degrees and roll 45 degrees, (d) pitch 45 degrees and roll 45 degrees

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 and also a relaxing state added. 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.

Motion Mode

We chose four swipe directions (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. Swipe directions are 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.

Results

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 finger posture (Motionless mode) and swipe gestures (Motion mode). In motionless mode, raw data is directly used for machine learning. 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. 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.

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%), and the confusing matrix is shown in Figure 5. Note that most of the error happened at the relaxing state and angle of pitch 45 degrees with roll 45 degrees. For relaxing, strains were slightly changed at 0.4N and 0.6N pressure, it is hard to be classified with other angle classes. For the angle, 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. The accuracy for each force level is shown in Figure 5, 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%).

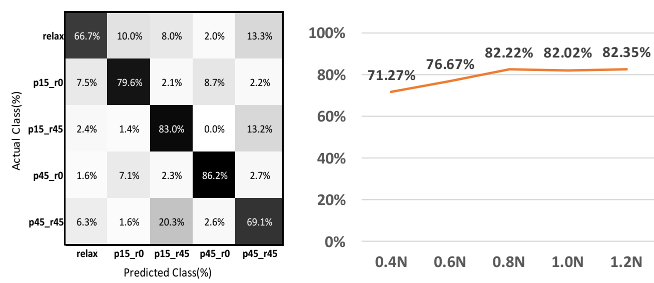

Figure 5: Motionless mode: Mixed-force confusing Matrix and Accuracy for each level of pressure.

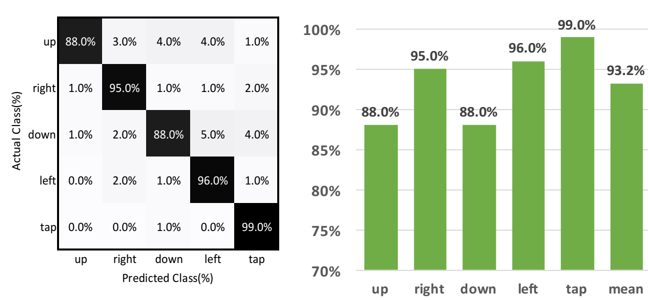

Figure 6: Motion mode: Confusing Matrix and Accuracy for four direction swiping and tapping.

Motion Mode

The result of this study is shown in Figure 6. 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 during swipe down and up gestures, likely due to the higher friction causing users to perform gestures lightly on the surface which caused strains on fingernail to become less observable for the sensor.

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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