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Fingernail with static and dynamic force sensing

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***Abstract*—We report on our development of sensorized fingernails for mechatronical hands. Our proposed design can capture static and dynamic interaction forces with the nail and provide basic information about the direction of the main force vector. Over the course of several iterations, we have developed a very compact working prototype that fits together with our previously developed multi cell MID-based tactile fingertip sensor into the cavity of a finger of a Shadow Robot Hand, a robotic hand roughly the size of an average male hand. High sensitivity combined with robustness for daily use are the key features describing our proposed design.**

I. Introduction

Only very few robotic hands have been equipped with artificial nails [1]–[3], which is surprising, as the fingernail plays an important role in human grasping and fine manipulation [4].

Human hands, especially the fingertips, have one of the highest concentrations of mechanoreceptors [5], the organs that sense mechanical pressure and distortions. We argue that the high sensitivity and the diversity of our touch receptors to be the key factor for us humans being able to grasp and manipulate objects with our hands so effortlessly. Recent advances in state-of-the-art tactile sensing in robotic hands [6]–[11] are a significant step towards robotic manual intelligence. Most previous attempts at sensitizing the robotic hands and fingers have gone into robotic skin development or sensing the forces and torques at finger, hand or wrist joints.

Only a single experiment is known to us, where the artificial fingernails were sensorized - in [12] Sinapov et al. present rudimentary fingernails, cut out of plastic sheet, that were equipped with three-axis digital accelerometers and were used to classify the surfaces contacted from the high-frequency signal induced during surface scratching.

II. Robotic fingernail with force sensing

Our design goal was to develop a miniature sensorized fingernail capable of vibratory and static contact force direction and magnitude measurements. As our *graspLab* is equipped with multiple Shadow Robot Hands, we chose to develop our fingernail prototype for this specific hardware.

The final design is a mechatronical fingernail for robotic hands, equipped with a multitude of sensors measuring static and dynamic interaction forces and the direction of the force

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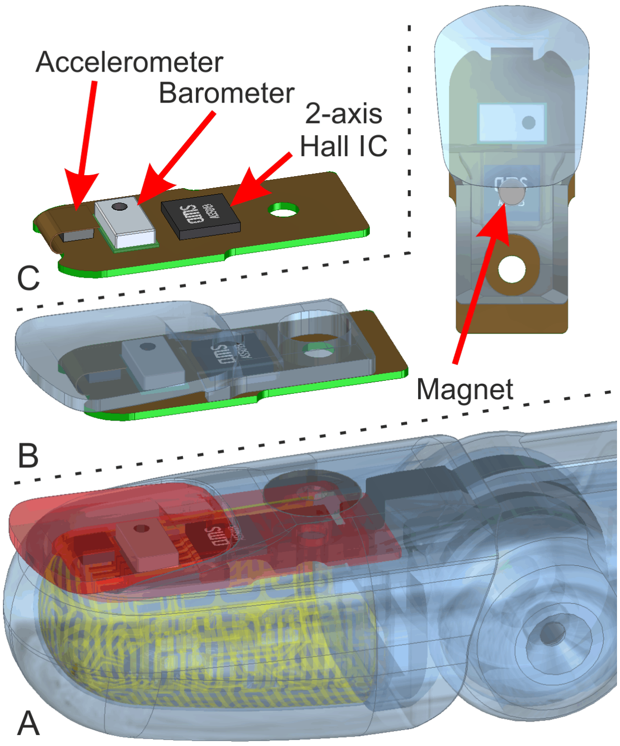

Fig. 1. **(A)** Novel fingernail sensor with multiple interaction force sensing channels (highlighted in red) and our previously developed MID-based fingertip force sensors [10] (shown in yellow), attached as customized fingertip for the Shadow Robot hand. **(B)** The sensorized nail is constructed from two parts - the rigid-flex PCB with digital sensor components and the minimally movable plastic semi-rigid nail, shown in translucent. **(C)** The rigid-flex PCB with an acceleration sensor, a barometer chip and a 2-axis hall sensor IC. All sensors are interconnected onto a shared digital I^2C bus and shared +3.3VDC power rail.

vector [Fig. 1]. Our fingernail design has two main parts - the fixed *rigid-flex printed-circuit-board (PCB)* with digital sensors in surface-mount-devices (SMD) packages as the base; and the nail part, CNC milled out of polyoxymethylene (POM) thermoplastic. The plastic nail is able to move minimally along the longitudinal and the lateral axes relative to the base, centered using silicon padding acting as spring.

Hardware description

All electronic components in our fingernail are connected to a shared digital I^2C bus, necessitating only a 4-wire connection to the fingernail (SCL, SDA and two supply pins). As the digitalization of the measured signals is located in each sensor, the design is very robust to electrical noise.

For measuring the fingernail deflection and thus the force amplitude on the longitudinal and the lateral axes, we opted for AMS AS5013 EasyPoint[1] two-dimensional magnetic position sensor chip due to its small size of only $4 \times 4 \times 0.55$mm and very high sensitivity. The AS5013 Hall-IC is measuring the planar deflection of the nail, where a $\varnothing 2 \times 0.8$mm neodymium magnet of type AS5000-MA2H-1 is press-fit into the prepared hole in the nail [Fig. 1B]. The nail movement in both axes of $\approx \pm 0.25$mm from its center position results in almost full range raw signal of roughly ± 120 digits in an 8-bit signed value range.

We measure the vertical push and pull forces exerted to the nail using two types of sensors - the static and the low frequency force is measured using a barometer chip, whereas the dynamic high frequency vibration, e.g. when scratching surfaces [12], is measured using an accelerometer chip.

For static force measurement we opted for Freescale/NXP MPL115A2 absolute digital pressure sensor. Inspired by Tenzer et al. [13], using under-pressure we filled the sensor and the gap area between the sensor and the nail with silicon [14]. The silicon filling propagates the mechanical forces on the nail into the MEMS membrane inside the sensor chip, originally designed to measure barometric pressure changes. Experimentally we found the fingernail normal direction threshold force over multiple trials to be very impressive $\approx$6 mN.

Our initial prototype used the absolute digital pressure sensor of type NXP MPL3115A2, a newer model of MPL115A2 with considerably higher internal analog to digital conversion resolution of 24-bits vs. only 10-bits of older MPL115A2. The orifice of MPL3115A2 is although only $\varnothing$0.5mm vs. $\varnothing$1mm on the MPL115A2, which resulted unfortunately in mediocre silicon injection and sub-par force transmission results.

For capturing the high-frequency vibrations of the nail, our initial prototype was using a wide-band MEMS microphone SPW0430HR5HB-B from Knowles. Although this worked amazingly well for capturing vibratory patterns, e.g. during scratching surfaces with the nail, similar to experiment in [12]; it also picked up sound (voices and noises) from the near vicinity of the fingertip. Our current model thus relies on Bosch Sensortec BMA255 acceleration sensor in tiny $2 \times 2 \times 0.95$mm package glued onto the bottom of the nail surface. The flexible PCB connection guarantees separation from the fixed base.

III. Discussion & Future Work

We have gathered initial test data from MPL115A2 barometric sensor and the AS5013 Hall sensor chip and the results look very promising. At the time of writing, we are just in the process of manufacturing the fingernail-base PCB with the BMA255 acceleration chip, as presented in Fig. 1, and are keenly waiting for the initial test results.

Plans are afoot to test the Melexis MLX90393 3-axial magnetometer, with the possible goal of being able to omit the barometric sensor and the tedious manual labor involved with vacuum silicon injection.

Although our design targets Shadow Robot Hand, the small size, the natural human-like shape, and the standardized I^2C electrical interface of the sensorized nail should allow it to be used with minimal effort on other robotic or prosthetic hands of typical human hand sizes.

[1] EasyPoint is a registered trademark of ams AG.

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