Hydrauio: Extending Interaction Space on the Pen through Hydraulic Sensing and Haptic Output

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ABSTRACT
We have explored a fluid-based interface(Hydrauio) on the pen body to extend interaction space of human-pen interaction. Users could perform finger gestures on the pen for input and also receive haptic feedback of different profiles from the fluid surface. The user studies showed that Hydrauio could achieve an accuracy of more than 92% for finger gesture recognition and users could distinguish different haptic profiles with an accuracy of more than 95%. Finally, we present application scenarios to demonstrate the potential of Hydrauio to extend interaction space of human-pen interaction.

Author Keywords
Human-pen interaction; finger gesture sensing; haptic feedback; fluid-based interface.

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);**

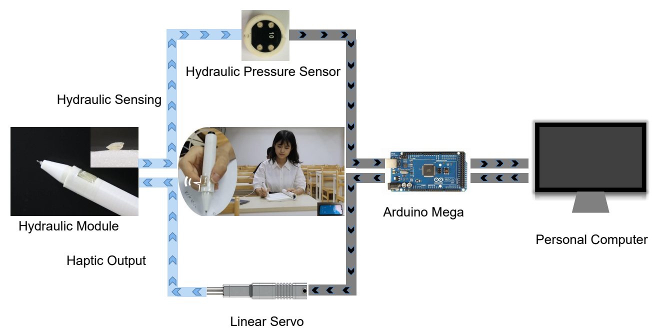

Figure 1. The overall hardware system

INTRODUCTION
Human-pen interaction has been a hot but well-established research topic for years. In order to extend the interaction space on the pen, researchers usually introduce finger gestures[13](eg. pen+ touch interaction[5, 1]) to expand input space or leverage novel output techniques such as haptic[8, 9, 10, 12, 15], auditory[3] or visual[14] feedback to enhance user experience. Besides, another way is to combine the pen with other devices such as a keyboard[11] or a handheld projector[2]. However, it is hard to adjust different application scenarios in this method. The last but not the least way is to modify the hardware composition of the pen itself, which is also the focus of many researchers in this area. For example, FlexStylus[4] is a new deformable pen prototype which could augment pen input through bend input. However, these techniques usually require to redesign the whole pen with high modification cost.

In this paper, we have explored a new interaction experience through introducing the fluid interface(Hydrauio) into human-pen interaction. The main difference that Hydrauio is distinguished from existing work is that Hydrauio could provide both input(8 finger gestures sensing) and output(8 haptic profiles) together, providing a richer user experience for a list of applications such as notification, drawing, tool selection, etc. TAKO-Pen[7] is a pen-type pseudo-haptic interface which is similar with ours. However, its force sensor and haptic display are separated with each other which take up more space on the pen and may affect users' normal use of the pen. Besides, it could not support finger gesture recognition and the haptic experience is different from ours.

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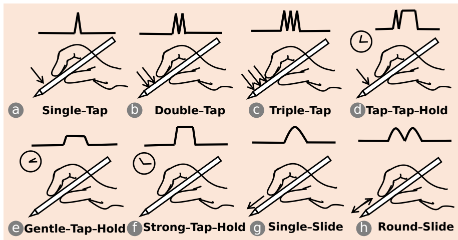

Figure 2. The 8 finger gestures for input and their corresponding curves.

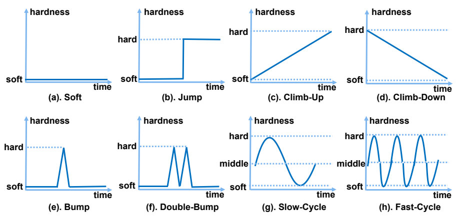

Figure 3. Curves of 8 haptic feedback profiles.

HYDRAUIO IMPLEMENTATION

The overall hardware system is shown in Fig. 1. The hydraulic driven module is set on the body of the pen where people's index finger is usually put when writing. This module is actually a tiny sealed water bag. A hydraulic pressure sensor is connected with the module through a pipe to capture pressure signals and a linear servo is also connected to control the pressure of the hydraulic module to provide haptic feedback to pen users. Arduino mega is used to transmit captured signals from hydraulic sensor to the computer.

To support finger gesture input, we have designed 8 finger gestures(Fig. 2) which are inspired by three basic gestures(tap, hold and slide) from the work of Jacob O. Wobbrock[16]. The curves of finger gestures are also shown in Fig. 2 which demonstrate the pressure change of the hydraulic module when users are performing different finger gestures. To recognize 8 finger gestures, we used KNN(K-Nearest Neighbors) with a metric of Dynamic Time Warping(DTW) to classify the time series data captured by the pressure sensor. We also have designed 8 haptic profiles to support haptic output to users, which are inspired by Frictio[6]. Five profiles are selected from Frictio [6] and we expand them to eight profiles in order to provide users richer experience. The relationship between hardness and time was shown in Fig. 3.

USER STUDY

We recruited 12 participants (3 female) aged 21- 25(all right-handed) from the author's institution to join in the user study which was composed of two parts: finger gesture sensing and haptic output recognition. In the first part, each participant was required to join in three separate sessions which were used for training, testing and cross validation. Test session evaluated the performance of the model trained from the training session and cross session evaluated whether the performance was good as well if users put down the pen and picked it up again. In the second part, participants were asked to distinguish different haptic profiles in three scenarios(Noise Cancelling, Music Playing, Writing). A headphone was used to cancel the noise and play music to participants. In the Writing scenario, the participants were asked to write anything they wanted on paper while they were using the pen to perceive haptic feedback.

User Study Part 1: Finger Gesture Sensing(Accuracy: %)

Finger Gesture	G1	G2	G3	G4	G5	G6	G7	G8
Test Session	0.98	0.97	0.98	0.84	0.99	0.7	0.94	0.95
Cross Session	0.99	0.99	1.00	0.83	0.98	0.60	0.94	0.95
User Independent Model	0.92	0.94	0.91	0.70	0.87	0.55	0.77	0.75

User Study Part 2: Haptic Output Recognition(Accuracy: %)

Haptic Profile	H1	H2	H3	H4	H5	H6	H7	H8
Noise Cancelling	0.99	0.95	0.96	0.99	0.97	0.98	0.97	0.97
Music Playing	0.97	0.98	0.92	0.96	0.99	0.95	0.93	1.00
Writing	0.92	0.97	0.93	1.00	0.98	0.97	0.88	0.94
All Sessions	0.96	0.97	0.93	0.98	0.98	0.97	0.93	0.97

Subjective Feedback

NASA TLX Score	Mental	Physical	Temporal	Performance	Effort	Frustration
Noise Cancelling	4.9	4.2	4.5	7.6	4.2	3.1
Music Playing	6.4	4.2	5.3	8.7	6	3.5
Writing	8.1	5.9	6.3	9.6	8	4.3

Figure 4. User study results.

Results. The results were shown in Fig. 4. G1- G8 and H1- H8 represented for the finger gestures and haptic profiles described before respectively. In the first part, we found that the accuracy of most gestures was closed to or higher than 95% in both Test and Cross Session. Finally, we used training data of each participant to train a model and used this model to recognize all gestures performed in the second session by all other participants. Then we calculated the results of user independent model in Fig.4. We could find that the accuracy of all gestures was higher than 70% except G6 *Strong-Tap-Hold*. The results of the second part were analyzed using two-way ANOVA tests. ANOVA yielded a significant effect of Mobility(Noise Cancelling, Music Playing, Writing)($F_{2,264} = 3.18, p = 0.043 < 0.05$) and Haptic Profile(H1- H8)($F_{7,264} = 2.09, p = 0.0449 < 0.05$). An interaction was also found between Mobility and Haptic Profile($F_{14,264} = 2.02, p = 0.0169 < 0.05$), indicating that mobility had an impact when users were trying to distinguish haptic profiles. The subjective feedback was collected from the NASA TLX form. From the result we could find that the workload increased when participants had extra tasks such as writing and listening to the music.

APPLICATION SCENARIOS

Hydrauio could support input control(finger gesture recognition) and output notification(haptic feedback). Besides, the combination of output and input could support more timely and direct human-pen interaction. More specifically, when users receive haptic output, they could perform finger gestures at the same position where they feel the haptic feedback as the response for input. At the same time, users may feel new haptic feedback as the response from the system.

CONCLUSION

We extended the interaction space on the pen body through allowing finger gesture recognition and haptic output leveraging the feature of a hydraulic module. A user study was conducted to validate the performance of Hydrauio. We finally provided example scenarios where Hydrauio can help users to extend interaction space on the pen and enhance user experience.

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