Back-of-device tap recognition by leveraging magnetometer in commodity smartphones

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***Abstract*—Tap inputs on the back of smartphones provide a solution to the occlusion problem but come with challenges such as reduced accuracy and constrained functionality. In this work, we introduce MagTap, a novel magnetic-based input interface for smartphones, specifically leveraging magnets and ferromagnetic materials to recognize tap inputs made on the back of the smartphones. Through our evaluation with a MagTap prototype on an Apple iPhone 12, we demonstrate that MagTap can achieve high localization accuracy (e.g., an average accuracy of 95.3% for single taps and 88.2% for double taps), not losing usability and deployability.**

***Index Terms*—Back-of-Device, IMU, Input interface**

I. Introduction

A touchscreen has gained popularity as the primary input method for the majority of smartphones. It supports simple and seamless interactions for smartphones; users are just required to touch somewhere on a touchscreen using their fingers. Despite that, using a touchscreen still causes a usability problem known as occlusion. For instance, when a user interacts with a touchscreen, a certain area of the screen is covered by his finger and thus the area becomes invisible to the user.

To avoid the occlusion problem, many studies have attempted to convert a smartphone's non-touchable space, e.g., the back of the device, into an additional input interface. Some of them [1]–[3] enable gesture-based inputs made at the rear of smartphones using only sensors integrated into commercial devices. Other works [4], [5] have explored the attachment of dedicated hardware to facilitate gesture recognition from the back of smartphones. However, these existing approaches come with limitations, such as reduced accuracy, constrained functionality, and reliance on specific sensors. Note that MagTap can be further extended to support more various types of tap interactions, such as double taps, by detecting multiple tap inputs made consecutively within a short time interval.

In this paper, we propose MagTap, a magnetic-based input interface that supports tap inputs on the back of a smartphone, while maintaining the smartphone's conventional form factor. Figure 1 illustrates how MagTap recognizes a user's tap inputs. First, we assume that a specialized array of magnets (e.g., MagSafe magnets [6]) are attached to or integrated into a smartphone. Users then tap somewhere on the magnet array using a tapping tool coated by ferromagnetic materials.

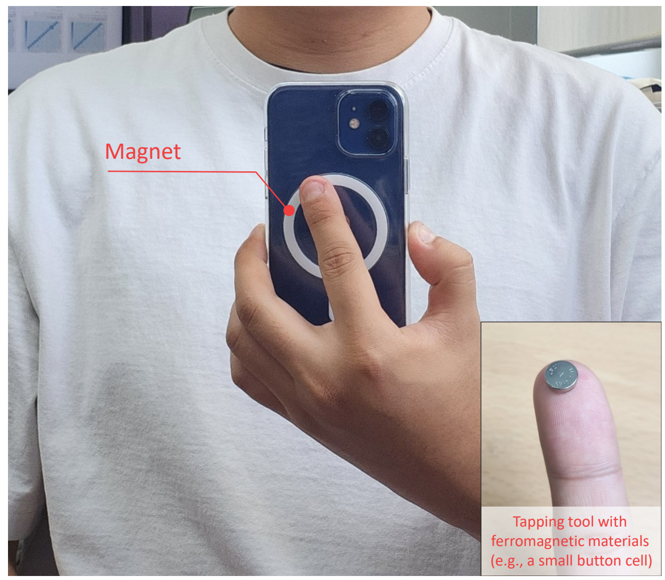

Fig. 1. Use case of MagTap

At this moment, the ferromagnetic materials are magnetized due to the contact with the magnet. MagTap then senses the additional magnetic field induced by the materials and eventually identifies both the presence and location of the tap input. Through our evaluation with the MagTap prototype on Apple iPhone 12, which is equipped with a MagSafe magnet, we demonstrate that it can precisely identify a user's tap inputs with an average localization accuracy of 95.3% (for single taps) and 88.2% (for double taps).

II. Related Works

Back-of-Device Interactions. Various studies utilizing diverse sensing modalities have been proposed to enable interactions from the backside of a device. Some works [1], [7] use the IMU (Inertial Measurement Unit) present in commercial smartphones to detect vibrations caused by taps, employing these vibrations for gesture recognition. However, this method is known to be susceptible to environmental noise. Other studies have proposed using acoustic signals, captured through a device's built-in microphone for gesture recognition [2], [8].

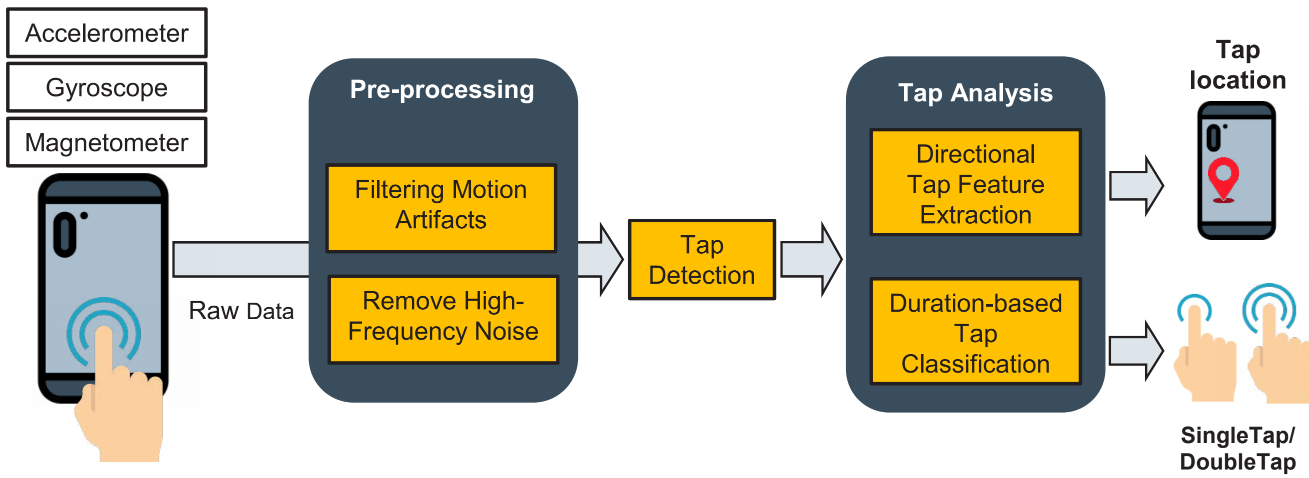

Fig. 2. System architecture of MagTap

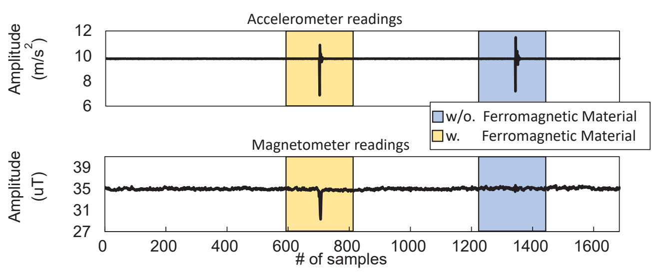

Fig. 3. Impact of Ferromagnetic Material on Tap Detection

These methods offer high accuracy in gesture recognition and localization performance but consume significant power due to their continuous acoustic sensing.

Magnetic-based Interactions. Similarly to MagTap, an input interface to leverage magnetism also exists [9]–[11]. One class of works [9], [10] employ changes in the magnetic field caused by the movement of permanent magnets around a smartphone. Another work [11] has designed a user-friendly input interface (e.g., button, slider, joystick) by combining a mechanical structure and magnets. However, using permanent magnets with strong magnetism near smartphones may damage the devices.

III. MagTap

Figure 2 illustrates the entire process of how MagTap recognizes tap inputs. It basically supports tap interactions; a user taps somewhere on the magnetic array integrated into the back of a smartphone by using ferromagnetic touch tools. When the tap input is made, MagTap collects not only the motion but also the magnetic recordings with using the built-in IMU sensors. It then detects a sudden fluctuation caused by the tap in those recordings (see Figure 3) and extracts the peak value of the fluctuation. The extracted value is then used for constructing a set of templates (in the calibration phase) or identifying the tap location (in the interaction phase). Note that in the interaction phase, we utilize an additional feature, called tap duration, to classify the input as a single or double tap.

Calibration step. During this phase, MagTap gathers templates that will be used for recognizing tap locations in the interaction phase. Toward this, we ask a user to tap four specific locations on the back of a smartphone, while collecting motion and magnetic data. More specifically, considering the trade-off between usability and data volume, we repeat this process just 25 times for each location.

Pre-processing step. To precisely detect and localize tap inputs, we first remove unwanted components from sensor recordings via frequency filtering. More specifically, we filter out high-frequency components ($>$ 5 Hz) of the motion and magnetic data obtained using the accelerometer and magnetometer, respectively. This is because tap inputs make fluctuations in the data with low frequencies.

Tap analysis step. We then detect the time range in which both the motion and magnetic data has sudden variations as shown in Figure 3 and extract the samples in the range. We call the extracted data *tap data*. Upon the acquisition of the tap data, we take its maximum peak value as the feature for tap localization, compare it with the templates obtained in the calibration phase, and finally determine the tap location. In addition, if two consecutive taps are detected within a time interval of less than approximately 400 ms, we classify them as a double tap.

IV. Experiment

We conducted several experiments to evaluate the performance of MagTap. In this experiment, we performed 100 single taps and double taps at each of the four different points on an Apple iPhone 12 using a tapping tool with a small-sized button cell. Figure 4 illustrates that MagTap can easily identify

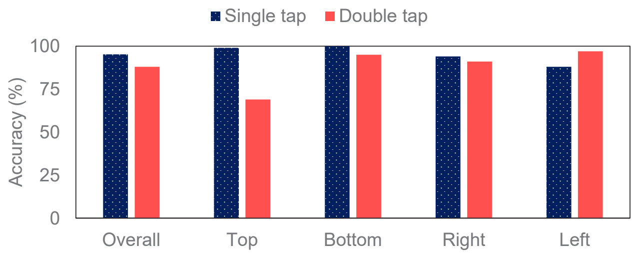

Fig. 4. Baseline results

the location of tap inputs with an average accuracy of 95.3% and 88.2% for single and double taps, respectively. Notably, the double tap accuracy at the top location is much lower than that for single taps. This is because the top position is relatively closer to the built-in IMU sensor compared to other locations, causing the tap to be detected for a longer time. Thus, the double taps are often misclassified as single taps. We believe that this can be resolved with more refined signal processing techniques in our future work.

V. Conclusion

In this work, we proposed MagTap, a novel magnetic-based input interface for smartphones, that leverages the ferromagnetic material's magnetization to enable tap inputs on the back of the smartphones. Specifically, to ensure accurate tap recognition, it employs a specialized array of magnets and small ferromagnetic materials, allowing detection and identification of tap inputs with an average localization accuracy of 95.3% for single taps and 88.2% for double taps.

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