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Wearable textile input device with multimodal sensing for eyes-free mobile interaction during daily activities

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HIGHLIGHTS

- Single-layer smart textile capable of capturing multiple sensing elements.
- Utilizing multimodal sensing to capture finger bending and pressing.
- Example applications with interaction design using proposed prototype.
- Performance evaluation under dynamic and eyes-free environments.
- Multitasking study to explore the prototype performance and perceived workload.

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ABSTRACT

As pervasive computing is widely available during daily activities, wearable input devices which promote an eyes-free interaction are needed for easy access and safety. We propose a textile wearable device which enables a multimodal sensing input for an eyes-free mobile interaction during daily activities. Although existing input devices possess multimodal sensing capabilities with a small form factor, they still suffer from deficiencies in compactness and softness due to the nature of embedded materials and components. For our prototype, we paint a conductive silicone rubber on a single layer of textile and stitch conductive threads. From a single layer of the textile, multimodal sensing (strain and pressure) values are extracted via voltage dividers. A regression analysis, multi-level thresholding and a temporal position tracking algorithm are applied to capture the different levels and modes of finger interactions to support the input taxonomy. We then demonstrate example applications with interaction design allowing users to control existing mobile, wearable, and digital devices. The evaluation results confirm that the prototype can achieve an accuracy of ≥80% for demonstrating all input types, ≥88% for locating the specific interaction areas for eyes-free interaction, and the robustness during daily activity related motions. Multitasking study reveals that our prototype promotes relatively fast response with low perceived workload comparing to existing eyes-free input.

1. Introduction

Modern smartphone and wearable devices have laid the foundation for the pervasive computing in daily life. Nevertheless, they still adopt a touch-screen based input method due to the limitation of vision and biosignal based sensing

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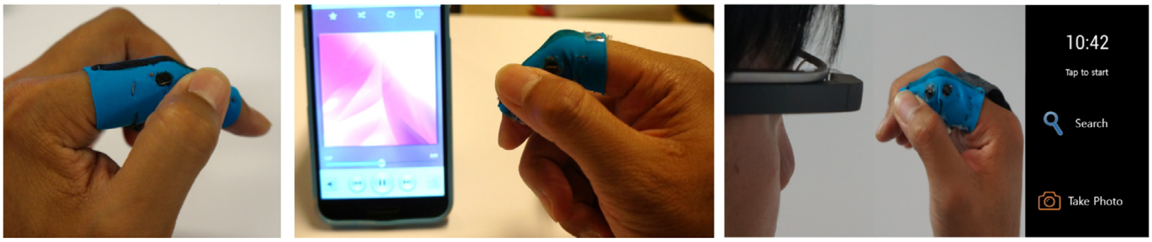

Fig. 1. Our prototype provides multimodal sensing through a single layer of textile to support eyes-free interaction during daily activities.

such as occlusions and motion artifacts [1,2]. The touch-based input requires users to switch their visual attention to the device while in use. However, splitting the attention during daily activities (exercising, driving, and working) causes falling, bumping, or traffic accidents [3]. Multimodal eyes-free interaction has a strong potential to prevent users from encountering dangerous situations by reducing cognitive/physical loads especially when access time for mobile devices is one of the key factor [4]. Wearables are found to be efficient in reducing the access time during the mobile interaction [5]. Thus, a multimodal sensing wearable device supporting eyes-free mobile input benefits users in terms of safety and accessibility.

Mobile interactions with various sensing techniques have drawn interest from researchers and developers to substitute the touch input [6]. Among them, smart textiles have been explored over the past decade as a solution for wearable devices due to the wearability and the soft texture [7]. By leveraging the material selection and fabrication, recent work has decreased the thickness of the smart textile while maintaining the performance [8]. However, previous works prefer implementing a single modal sensing for measuring passive inputs such as event recognition [9]. With a single sensing element, it is hard to provide a rich enough data to fulfill the input taxonomy needs of the state-of-art mobile devices. To this end, we explore a smart textile which is capable of supporting multimodal sensing capability as an input metaphor.

In mobile interaction, the hand embodies complex gestures with high precision and flexibility, and has been a key input mechanism. Within a hand, the most frequent interactions are created by the fingers [10]. By leveraging the use of fingers, previous works highlight performing rich interactions while maintaining a small wearable form factor as a pervasive input metaphor [11–14]. Although these techniques support pervasive computing, their approaches are not designed to work under dynamic environments including exercising, driving, or working. Moreover, the physical components used in these techniques make users hard to keep the natural hand posture while in use. To guarantee the performance in real environments, a finger-type device should properly function under various activities.

In this work, we present a multimodal sensing technique by merging strain and pressure sensors on a single layer of the textile (Fig. 1). Based on two different sensing modalities, we define two types of finger motions: finger pressing and bending. We employ a two-phase and a polynomial regression analysis to model the relationship between magnitudes of pressure and strain against applied finger pressing and bending. By using a multi-level thresholding, we capture different magnitudes from pressure and strain sensing. The swipe gesture is captured via the temporal position tracking algorithm. In total, 14 or more distinct inputs can be created with two-finger interaction. The prototype consists of elastic and soft materials to better preserve and improve the tactility and the wearability compared to attaching hard and rigid components. Use of elastic textile which induces pretension upon wear enhances the system robustness by correcting the initial offset values as well as providing stable fixation onto the body. Our initial results were first reported in *ACM UBICOMP 2014* and *ACM TEI 2015* [15,16]. Since then, we have completed interaction design process for demonstrating example applications. Extensive user studies have been carried out to evaluate the system performance during dynamic activity, eyes-free environment, and multitasking. Furthermore, we have compared the proposed prototype with other conventional input devices to get both quantitative and qualitative feedback from users. Our contributions include:

- Developing a single-layer smart textile capable of capturing multiple sensing elements during activities
- Utilizing multimodal sensing values from fingers to capture bi-directional swipe and different levels of finger bending and pressing
- Example applications with the finger-worn wearable prototype demonstrating rich eyes-free interactions
- User study to explore the performance of the proposed system under dynamic and eyes-free environments
- User study to explore the prototype performance in accuracy and reaction time as well as perceived workload comparing with existing input devices during multitasking

The rest of this paper is organized as follows. Section 2 discusses related work from the previous work. Section 3 describes the system design, preliminary experimental results, and example applications with corresponding interaction design. Section 4 offers user study results and implications from quantitative and qualitative data. Finally, conclusion and future work are discussed in Section 5.

2. Related work

Wearable input device: Wearable input devices provide significantly faster access time to interact with mobile devices [17]. With an advancement in sensor technology, small and powerful wearable input devices have been introduced.