Smart Footwear Feedback Interface Analysis and Design

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***Abstract*—Human gait and posture have been considered one of the most important health indicators. Therefore, more and more smart footwear put stress on posture correction and gait analysis.**

In our research, we developed a smart footwear feedback interface to help user correct posture instantly. Furthermore, we designed multiple instinctive vibration modes specifically for correction information in order to avoid the attraction by noise in real world and also improve the accuracy for posture correction.

We simulate an application scenario to verify the accuracy of vibration modes. The experiment result shows the vibration feedback interface that we design is easy to recognize. We reached 79% accuracy in average and it only needs 2.6 seconds to recognize.

Keywords—Smart footwear, Real-time feedback, Haptic, Gait correction

I. INTRODUCTION

We are able to see many applications of Quantified Self [18], Life Log [2] and Sousveillance [9] in many international exhibitions and seminars, such as Computex, MWC and CES International Consumer Electronics Show in 2015. Lots of exhibitors have applied above concepts to design smart wearable products or service such as smart clothes, watches and bracelets for sports and health. With the rapid growth of quantified self application, people begin to focus on monitoring their own health. However, we found human gait and posture have been considered one of the most important health indicators [14].Relevant footwear manufactures like Nike [3], Adidas [1], Moticon [10], Plantiga [12] and Stridalyzer [13] have also announced new smart footwear products which put stress on real-time posture correction and injury prevention service.

In order to correct users' posture and gait, smart footwear products usually provide feedback, such as giving tips about wrong posture or guiding users to make the right action through visual, auditory or tactile ways. In fact, real-time feedback for helping users adjust their posture on wearable devices has been widely used in sports and health. Takahata et al. [18] designed a karate training system which teaches user to punch at the right time with sound feedback. The devices are put on the wrists, ankles and waist to detect users' movement. Moreover, Spelmezan [17] set pressure sensors in a skate board, thereby detecting the user's focus shifted in skiing. They choose vibration feedback to try solving a problem which ski instructor is unable to guide beside immediately. Hijmans et al. [7] designed a footwear feedback system to avoid damage caused by diabetes. The system set four pressure sensors and four vibration motors into the insole to realize pressure distribution of foot. When the system detect abnormal status, it will activate the vibration motors to notify user adjust their focus. In order to reduce the chance of knee osteoarthritis, Shull et al. [15][16] developed a vibration feedback method to try decreasing knee adduction moment (KAM) by changing the tibia angle and foot progression angle. Dowling et al. [6] guided users to change focus with auditory or tactile feedback which objective is to reduce knee adduction moment. After compared with the experimental results, they found out the effect of tactile is better than auditory. Spelmezan [17] and Chen [5], who sums up different real-time feedback researches, and pointed out that the visual feedback will distract users' attention and bring more danger in exercise. In addition, auditory feedback is susceptible to outdoor noisy that cause message cannot be delivered. On the contrary, tactile does not distract users' attention as well as susceptible to environmental interference. However, vibration feedback cannot transmit too complex message.

After researching past studies and smart footwear application, we can find out most of them are utilized in sports and health. Comparing with other ways of feedback, tactile feedback is much more suitable for smart footwear device. However, there were no researches which aim to integrate the tactile feedback with smart footwear device. This study focus on designing a feedback interface for smart footwear device. We summarized some researches in order to find the gait which need to be changed, then we design intuitive vibrational feedback instructions for each of them. The proposed feedback interface may help users adjust their focus and gait instantly during in exercising or daily life, furthermore, it can be apply to interactive entertainment, health care and medical.

II. METHODS

In this section, we will describe more detail about the concept of our research and design experiment to verify the methods. There are thirty healthy subjects participated voluntarily in the experiments.

A. Feedback Content

Before we design the feedback interface, we should define what messages that user needs to know. For the reference about smart footwear product and research we mentioned before, we found that helping users adjust the focus and gait is the most important things about smart footwear. Therefore, referring to some researches [6][16][20], we summarized

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some movements with gait rectification. Then we determined these data to be the feedback content in our research, as show in TABLE 1.

TABLE 1. Item of feedback content.

Item	Content
Gait Rectification	• Toes in or out • Distance between the feet step width • Taking longer or shorter strides
Focus Prompting	• Point out the excessive pressure position of foot

B. *Feedback Design*

We intended to design the feedback interface with simplicity and instinct, therefore, the vibration feedbacks should not transmit complex messages. We refereed Chen [4] and Hijmans [7] study which place four vibrating motors on insole that correspond with the main foot pressure positions. These four positions have also covered four directions (forward, backward, left and right) of the foot. The four positions a, b, c, and d, as show in Fig. 1.

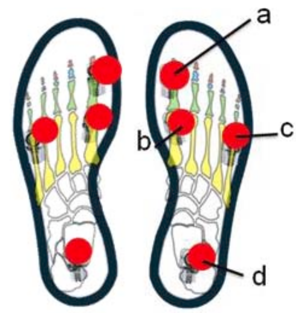

Fig. 1. Position of vibration motors.

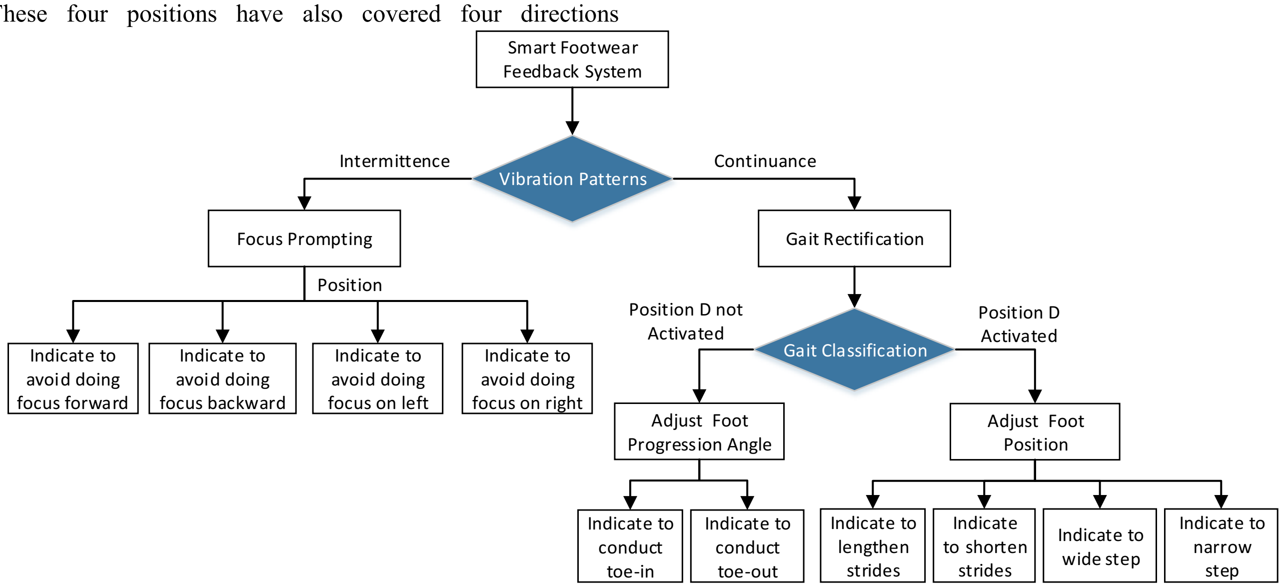

Fig. 2. Smart footwear feedback interface architecture.

As show in Fig. 2, for helping users identify which type (gait or focus) needs to be adjusting quickly, we designed two different vibration patterns. When the vibration pattern start to intermittent means focus needs to correct, then the vibrating motor will pause and reboot for couple of times. On the other hand, if user needs to adjust their gait, vibrating motor will be triggered continuously.

According to the difference of adjustment type, gait rectification can be divided into two types; one of them is modify the position of the foot, such as changing distance between feet step width and strides, the other one is adjust rotation angle of the foot, such as toe-in or toe-out. Therefore, we designed a mechanism to help user distinguish these two types intuitively. Rancho Los Amigos the Analytics Association defined that there are eight phases [8][11] of human walking behavior. As show in TABLE 2, we know that heel touching the ground is the first phase of human walking. Thus, we defend the vibrating motor of position “d” to be the flag.

TABLE 2. Fundamental gait phases and expected sensor signal patterns description.

Phase	Name	Description
1	Initial Contact	The heel starts to contact the ground.
2	Loading Response	The forefoot and the heel start to contact the ground.
3	Mid Stance	Inside of the forefoot touches the ground.
4	Terminal Stance	Center of body mass moves forward and the heel starts to take off.
5	Pre-Swing	Only the thumb toe part touches the ground.
6~8	Swing Phases	The foot does not touch the ground.

1) *Focus Prompting*

In this paper, we use four different positions of vibrating motors to point out the error of focus placement.

Vibration modes of adjust focus:

1. Indicate to avoid doing focus forward (Focus Forward): Vibrating motor at position “a” activate with intermittence pattern.

2. Indicate to avoid doing focus backward (Focus Backward): Vibrating motor at position "d" activate with intermittence pattern.
3. Indicate to avoid doing focus on left (Focus on Left): Vibrating motor at position "b" activate with intermittence pattern.
4. Indicate to avoid doing focus on right (Focus on Right): Vibrating motor at position "c" activate with intermittence pattern.

2) Gait Rectification

If the vibrating motor at position "d" activated, means user need to adjust the position of the foot. Otherwise, if the vibrating motor at position "d" not activated, means user need to adjust the progression angle of the foot.

Vibration modes of adjust foot position:

1. Indicate to wide step (Widening Step): Vibrating motor at position "b" and "d" activate with continuance pattern.
2. Indicate to narrow step (Narrowing Step): Vibrating motor at position "c" and "d" activate with continuance pattern.
3. Indicate to lengthen strides (Lengthen Strides): Vibrating motor at position "d" activate with continuance pattern.
4. Indicate to shorten strides (Shorten Strides): Vibrating motor at position "a" and "d" activate with continuance pattern.

Vibration modes of adjust foot progression angle:

1. Indicate to conduct toe-in (Toe-In): Vibrating motor at position "c" activate with continuance pattern.
2. Indicate to conduct toe-out (Toe-Out): Vibrating motor at position "b" activate with continuance pattern.

C. Feedback Sorting

Gait keeps changing intricately when people walk on the streets. That might be happens like focus is forward too much and toe is towards outside too much at the same time. Moreover, sometime people may need to lengthen their strides and reduce the step width at the same time. After considering all improper gait and focus presented in the paper, there will assemble a large number of gait prompt combinations. If we design a specific tactile introduction for each situation, the user will need to remember a variety of different commands. It would create a huge burden and confusion.

In order to avoid memorizing too much vibration mode, we planned a simple and intuitive feedback method which is sorted by the service type and the influence degree. The feedback system will only give one priority vibration mode time until all the feedbacks are given.

For example, if there are three adjustment feedbacks need to be given at the same time and the order of their importance will be conducting toe-in, narrowing the step width and the focus is too left, Based on the priority to give Toe-In feedback then recalculate the order and give the next feedback.

D. Experiment

In order to verify the accuracy of vibration modes for this feedback interface, we design a vibration feedback insole which has four vibrating motors, and plans a set of experiments.

The experimental subjects are thirty people who aged between 25 to 30 years and mean weight are 67.6 kg. To stabilize walking speed, the experiment is carried out in a gym, and the subjects will be asked to walk on the treadmill; meanwhile, the speed will maintain at 4 km / hr to simulate walking scenario, as shown in Fig. 3.

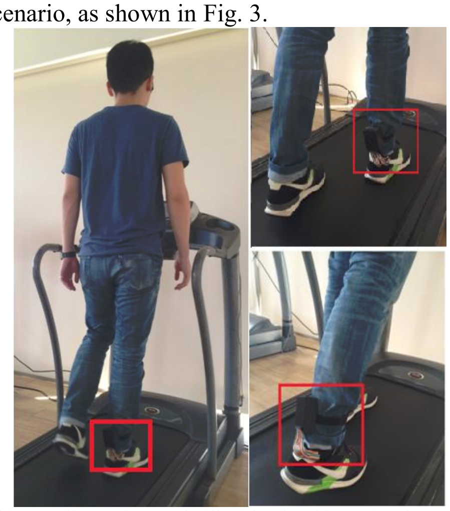

Fig. 3. Subject walks on the treadmill with 4 km / hr to simulate walking scenario.

1) Experiment Process

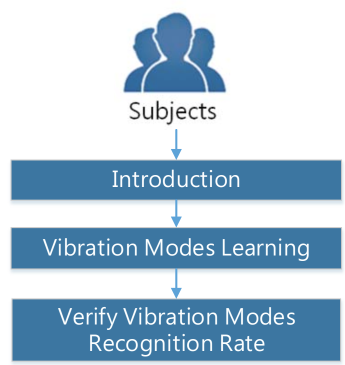

Fig. 4. Experiment process.

As show in Fig. 4, at beginning, subjects will wear the vibration feedback insole and walk on the treadmill. In the meanwhile the observer will introduce the four focus prompting and six gait rectification vibration modes. Then let the subjects feel the various vibration feedbacks actually.

In order to validate the accuracy of vibration modes, we design another experiment. The observer will execute ten kinds of vibration modes randomly. At the end of each vibration, subjects are required to answer the name or meaning of the vibration modes with no time restriction. They are also allowed to answer " Unrecognized" if they are unable to recognize. The answers and the recognition time will be recorded.

2) Hardware and Software Design

A part of vibration feedback insole is shown in TABLE 3. The voltage range of vibration motor is from 2.7V to 3.3V. If the voltage is higher, then the vibration amplitude will be greater. The insoles connect to mobile devices by bluetooth low energy (BLE), receiving vibration motor control signal. The vibration feedback insole as shown in Fig. 5.

TABLE 3. Parts of vibration feedback insole.

Item	Company	Product Type
Control IC	Arduino	Arduino Pro Mini 328P
CPU	Atmel	Atmega328P
Vibration Motor	KOTL	C0834B002F

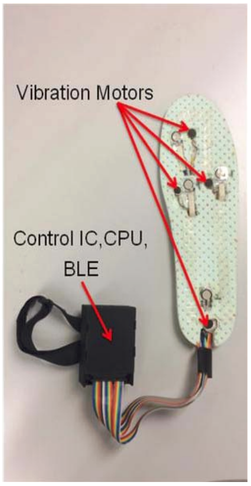

Fig. 5. The vibration feedback insole.

We develop an android application to control the vibrate modes of feedback insoles. After connecting smart phone and insole, observer click the vibration modes button to set modes and execute the program. The program will executing until subjects answer the vibration modes. Recognition time is recorded since program started until subjects answer.

III. Experiment Result

As shown in Fig. 6, the average accuracy of vibration modes is 79%. The accuracy of focus prompting are 83%, and we get only 76% at gait rectification. Among them, the accuracy of foot progression angle adjusting are 83%, and foot position adjusting are only 72%. For all vibration modes, Focus Forward get the best accuracy of 100%, on the contrary, Focus on Right, Narrowing Step and Lengthen get the worst accuracy of 66%.

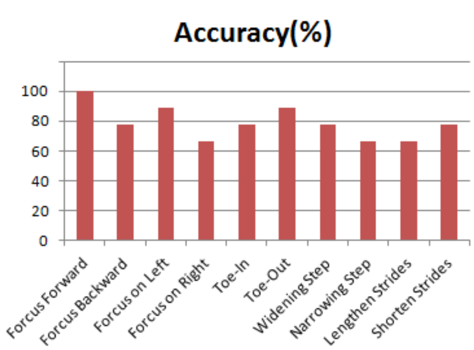

Fig. 6. Vibration modes accuracy verification result.

As show in Fig. 7, the average time for recognizing vibration modes is 2.6 seconds, and it takes only 4.8 seconds at most. Therefore, the recognition time of focus prompting are all less than gait rectification. The average recognition time of focus prompting are 1.9 seconds, and gait rectification are 3 seconds. Among them, the different of recognition time between foot progression angle adjusting and foot position adjusting are only 0.3 seconds, it' s no significant differences. In all vibration modes, Focus Forward takes the least time of only 1.7 seconds, and the Narrowing Step and Shorten Strides takes 3.2 seconds.

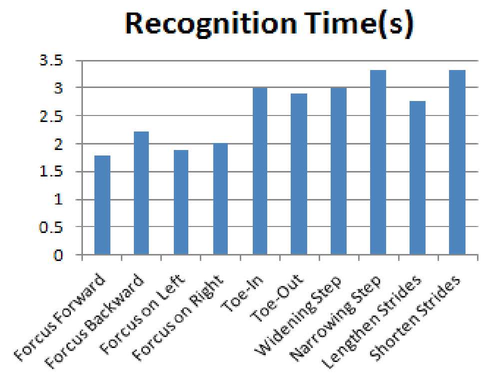

Fig. 7. Vibration modes recognition time statistical result.

IV. Conclusion

This study intended to develop a smart footwear feedback interface that can help users quickly and intuitively adjust their gait and focus in real-time. In order to avoid the feedbacks interrupted by ambient noise or distract users, we abandon the auditory and visual feedback design to apply a vibrating feedback interface.

The experiment result shows the vibration feedback interface that we design is easy to recognize. We reached 79% accuracy in average and it only needs 2.6 seconds to recognize. However, there are still some vibration modes such as Focus on Right, Narrowing Step, Shorten Strides and Lengthen Strides which are difficult to recognize.

After reviewing subjects' opinions and our hardware design, we found that the distance of vibration motors between position "b" and "c" in Fig. 1 is so close that subjects may be confused. Especially the motor at position "c" seems to be too close to the insole center, in which lead to mistake of recognition, for example, Focus on Right is recognized as Focus on Left or Toe-In is recognized as Toe-Out.

Moreover, based on the experiment results, the performance of focus prompting is always better on both accuracy and recognition time than gait rectification, especially in recognition time, the differences can reach 1.1 seconds.

Refer to subjects' advices, we know when two vibrating motors activate at the same time, subjects would be confused to identify the vibration modes easily so they were not able to accurately identify the vibration modes. The accuracy of vibration modes reduce obviously when more than two vibration motors are activating at same time, and recognition time are rising, as show in TABLE 4.

TABLE 4. The performance of motor number that activating at same time.

Motor Num	One Motor	Two Motors
Accuracy	80%	74%
Recognition Time	2.3s	3.2s

In the future, we expect to further solve the misjudgment problems caused by activating two vibration motors at the same time. Intermittent and alternate vibrations which keep only one motor activate at one time would become a new type of foot position adjusting methods. In addition, we will revise the position and amplitude of vibrating motor to raise the performance of smart footwear feedback interface.

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