用于盲人室内导航的肩部震动反馈系统，以及反馈策略的研究

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Shoulder vibration feedback system for visually impaired people indoor navigation, and the study on the feedback strategy

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Abstract

3% of the world population have severe visual impairments and 0.5% of the world population are completely blind. Personal accessibility devices are still needed today to assist their mobility. Navigation systems for visually impaired people contains sensing, calculating and feedback elements. This work presents a shoulder vibration based haptic feedback system and its feedback strategy design.

To address the problem "How to provide the vibration feedback on shoulders", I proposed a human factor driven research method. The system constrains and variables are clarified. The variables defined the solution space. The cognitive limitation will be measured by building a hardware platform perform above human limitation and conducting evaluations of how users' response to different combinations of the variables. The optimal combination will be applied following the human factor study results. The final system will be evaluated under another set of metrics to compare with other solutions.

The potential contributions of this work are: 1) The human factor study result that can guide future design in this problem space. 2) The technical solution that enables high definition vibration feedback. 3) A feedback solution with overall better performance in VIP indoor navigation tasks.

Key words: Visually impaired people, Accessibility, Indoor navigation, vibro-haptic feedback

Contents

Chapter 1 Introduction

1.1 Background

In 2015, among the 7.33 billion people living in this world, an estimated 3% had moderate to severe visual impairment. And near 5‰ of the global population were completely blind[1]. The disability caused by visual impairment is a problem of the whole society. With enough infostructure, people with visual impairment (VIP) should be able to enjoy the life as all do. However, building up accessibility everywhere is not possible yet due to a lack of consideration and lack of resources. The problem of lacking infostructure is more severe in developing countries such as china. Making it difficult for visually impaired people to live normally. Besides infostructure, guide dog is also helpful for those in need. But the majority of VIP cannot get one because of the time and effort needed to train a guide dog. Though we should not see disability as a problem from the people, we still need to put effort on the people side to deal with it. That is where the assistive technologies come in.

1.2 Problem Statement

People with visual impairments have lots of problems to deal with in their daily life. Those problems include but are not limited to walking around, finding lost items, distinguish items without tactile labels, interacting with GUI, taking to others without gestures and face expressions. The aim of this work is to help with the first one, helping VIP walking in public spaces. The reason for this choice is that walking is a basic element for a person to be a part of the society. And a lot of other tasks are related to walking.

Building a navigation system can be understood as building a self-driving system for people. The problem can be divided into three topics. Understanding the environment, meaning gather information from all channels using varies sensors. Decision making, process all the information and decide what to do next. Executing, in this case, provide feedback to the user and “tell” the user what to do. This work will focus on the last part, on providing better feedbacks to the user. A certain scenario is required for evaluating the feedback system. Here I choose to tackle the indoor open space navigation. This problem can be further split into two tasks, rotating to the desired orientation and keeping straight toward the destination.

A combined haptic and audio feedback had been applied to this problem for more than ten years. The major difference between the works are the design of feedback logic, including the audio and haptic scripts, the method of haptic feedback and where the haptic feedback is taking place. More details will be discussed in the literature review section.

1.3 Research Significance

I believe a good vision is the only thing that could be taken away from people with visual impairments, not their rights to live a normal life. During the interview held by my coworkers with visually impaired people in Beijing, we asked them what the thing is they want most. And the answer is “to walk around in the streets”. The fact that 5‰ of us is completely blind is always forgotten because they are not out here with the rest of us. They are terrified of going out because the society is not designed for everyone. There are too much unknowns waiting for them. Since our society can not change in a short period of time, I think it is still necessary to arm the visually impaired people with the latest technology, to extend their ability and give back their normal life.

VIP navigation problem is a broad problem space. And my work will focus on the study of the feedback. And focus on the single form of feedback – vibration feedback on shoulders. Though the project, I will first conduct a human factor study to learn the limitation of human in this system. And then design and build the feedback system according to the findings. During this process, new technologies in this filed will be applied. And this work will be compared to other solutions in this problem space to evaluate the performance.

Chapter 2 Literature Review

In this section, the existing works will be classified according to their physical forms. Since the physical form is the foundation of the haptic feedback.

2.1 White cane

White cane is a useful tool for visual impaired people to detect landmarks and obstacles on the road. Since it is frequently used by the users, a lot of VIP mobility work focused on improving the current functionality and experience of the cane. Those works often integrates both sensors and haptic feedback components in their smart canes. Here we will concentrate on the feedback side. Guide-Cane[2] is an electronic cane with a wheeled robot connected to the far end. The feedback is the drag force provided by the steering of the robot. This approach is direct and effective. However, due to the age of this work, the robot on the cane is bulky. This work represents one way to provide force feedback on any devices. Thanks to Newton, we all know that there need to be an opposite force somewhere else to apply a force to the user. The Guide-Cane did that by adding a robot into the system. The other way can be seen in a much more recent work[3]. In this work, the researches built and tested a smart cane for VIP to navigate in VR environment. The cane is not contacting the ground or any object. Instead, it is connected to the user's body via a complex mechanical structure. This structure can simulate what the cane is supposed to react while contacting items in VR. With both audio and force feedback. This work implemented force feedback by putting the other end of the force on the user. And that is the reason for the complex structure. Another approach of enhancing the white cane experience is to apply vibratory feedback[4]. Since for the user, there is only one point of contact while using the cane, the information from the vibration is very limited. In previous work it is restricted to providing notifications of obstacles.

As a conclusion. Force feedback can provide rich information, but the downside is the complexity of the mechanical structure to generate the force. While vibration feedback is the opposite. And for the cane formfactor, it is important for the VIP because it is the existing haptic feedback (without any enhancement) they have. It can provide the user a sense of safety to relay on him/herself to detect the road condition. I think the cane is hard to be removed from a VIP navigation system. And there are few reasons to do so. Thus, the feedback system in this work should be able to work with a traditional cane.

2.2 Insole

Simulating touch is one of the ultimate goals of haptic feedback. And vibro-tactile insole is one approach for this. Researchers tried to communicate information through foot sole by applying a vibration motor matrix inside the insole[5]. For their first version of prototype, they put 16 units in the insole. However, the sensitivity of the foot sole is not high enough. Thus, in the second version, they reduced the motors to only 4, representing the four directions. And they got an average accuracy of ~85% for separating the four directions. They also tried to represent words by certain vibration pattern. The result is not good, and I do not think this approach is meaningful. From this paper and my understanding, foot sole only suits for two points feedback. Multiple vibrations in on one foot will cause cognitive burden and will not be accurate enough.

2.3 Wristband

Haptic feedbacks on wristband is the most popular commercialized solution in wearable devices. And researchers also used this in navigation tasks[6]. In this work they applied four vibration motors on one wrist band. And used this single wristband setup for navigation. Those four vibration motors provide directional information to the user. Six direction areas are represented using different vibration combinations. The tests showed a 72% accuracy for recognizing the direction within 10 degrees. There is another way of utilizing the tactile feedback on the wristband. In a previous work[7], the researchers used two vibration wristbands to indicate left and right turns for navigation. Providing the information of the accurate direction can increase the efficiency of a feedback system.

2.4 Jacket

Haptic jacket is an approach for providing large area upper body tactile feedback. A recent work[8] done by researchers from MIT and CMU presented an airbag jacket able to provide force and vibration feedback. The jacket contains several inflation airbags and is connected to a pressed air system. The force feedback is achieved by adjusting the air pressure inside the airbag. And the vibration feedback is done by changing the air pressure rapidly. The force applied on the user body is accurately controlled via a closed loop control system enabled by a force sensor on the surface of each airbag. This jacket is capable of simulating varies experiences including "punch, hug and a snake moving across the body.". They also proposed the potential usage of this devices in VR applications. And if the size of the device can be small enough to carry, it may be a good choice for providing feedbacks in VIP navigation.

2.5 Electrode

Sending information by electrify the user is a bold idea. Typically, under the human safe voltage, there should not be enough current to be sensed by the human body. However, if the electrode is put inside the body where the resistance is lower, the low voltage signal can be sensed. And that is what the researchers did in this work[9]. They put an electrode matrix inside the mouth and "electrified" the user. The applied voltage on different part of the tongue to indicate different directions. And they get a 100% accuracy on representing the four main directions using this method. Hiding the feedback mechanism inside the body maybe a good idea for privacy concern. But this method arises severe safety concerns for applying voltage inside the mouth. The current will generate heavy metal ions and potentially will interfere with the nerves.

2.6 Belt

Waist is another body part that is sensitive to vibration. And it has the advantage of a natural 360 degree "interface". Which makes it possible to simulate obstacles around the waist. Related works often uses a relatively large amount of vibration actuators (typically 8) to generate the feedback[10, 11]. The advantage of using multiple actuators is a higher information density. The tactile belts can use "animations" to inform the user about directions or obstacles. In the related research, researchers used two metrics to evaluate the performance of the belt. The direction accuracy (8 direction) and the reaction time. Those metrics can be applied to this work to evaluate the feedback system. The formfactor of belt enabled a richer information. The downside is that the system can be a little complex and the complex information has a higher possibility to confuse the user. Overall, belt is a good approach for providing the haptic feedback in navigation.

2.7 Overview

Table 1 Overview of haptic feedback methods

Method	Pros	Cons	Take away
Cane (robot)	Force feedback	Large	Solution should be compatible with white cane
Cane (VR)	Force feedback	Large	
Cane (vibration)	Simple	Limited information	
Insole	Simulate road	Not sensitive	
Wristband	Direction	Low accuracy	Direction info is important.
Two wristbands	Simple	Limited information	
Jacket	Rich information	Large	Compact formfactor.
Electrode	High accuracy	Dangerous	
Belt	Rich information	A little complex	Compatible with belt

Chapter 3 Research Approach and Evaluation

3.1 Clarification for the topic

3.1.1 Where to apply the feedback

There are two major concerns for selecting shoulder as the “receiver”.

1) The design constrains.

In this system, I want to take advantage of the body movement information collected by the feedback system. In order to construct a better feedback strategy. Therefore, the movement of the body part must represent the movement of the person. This constrain limited the “receiver” to be part of the trunk of head.

2) Prior test on vibration sensitivity.

To further select the “receiver”, a prior test is done to study the vibration sensitivity of body parts on the upper body. The result is shown in the table below.

Table 2 Sensitivity test result.

Part	Comment
Earlobe	Not sensitive. Distractive noise.
Back of the ear	Highly sensitive. Intense distractive and uncomfortable noise.
Shoulder	Highly sensitive on clavicle.
Upper arm	Not sensitive.
Belly	Sensitive.

3.1.2 What formfactor should be used

From the literature review, we can get the conclusion that the form of the feedback device is bonded with where the feedback will be applied on. Meaning the choices of formfactor is limited once the body part had been chosen. Meanwhile, the formfactor will dramatically affect the implementation of the feedback. In this project, I chose to embed the feedback system inside the backpack straps because it has a natural interaction with the user’s shoulders. And it also made it easier to put the rest of the system inside the backpack.

3.2 Research method

The root problem to be solved in this work is how to provide the vibration feedback on shoulders. The following research methods are scoped for solving this problem.

1) Clarify the constrains.

Make clear of the system constrains in this problem and in this solution.

2) Clarify the variables.

What can I modify and what will change according in this solution.

3) Find out the limitation of human.

Study what is the cognitive upper limit of the user in order to build the most effective feedback system. This step has two requirements. The hardware that can perform above the human limitation. And a set of metrics for evaluating how the user response while using the feedback system.

4) Build the feedback system accordingly.

5) Evaluate the solution.

To evaluate the solution, it needs to be compared with other solutions in the same macro problem space. That requires a set of metrics that has been used and can be applied to this project to evaluate this project's overall performance.

3.3 Clarify the constrains

3.3.1 The constrains of vibration

Vibration will be the only feedback method involved in this feedback system. And the limitations of vibration feedback need to be made clear. Vibration is much less rich in information compare to audio. It is not rational to encode complex meanings via vibration. That can be proofed in the insole design that is reviewed earlier. Vibration's advantage over audio is the ability to provide continuous feedback but not on the complexity of information.

3.3.2 The constrains of two macro points

Since the feedback will be applied to the two shoulders of the user, there are only two macro points of interaction. Though the feedback on each point can be modified in many ways, this is still a constrain of the feedback system. A direct representation will be difficult to achieve in this solution due to that. The direction information will likely to be represented in the form of turning angles.

3.4 Clarify the variables

3.4.1 Latency from sensing to decision

This latency is not visible in laboratory environments because the researchers will make sure there is more than enough calculation power to run the decision-making algorithm in real time. However, that is not the case in real scenarios. This latency is determined by the workload of the algorithm, the calculation power and the communication latency of the whole system. In laboratories, this latency may only be several milliseconds caused by the frame rate limitation of the cameras. If the calculation happens on the cloud, the communication latency along can be up to the scale of 100ms, which will be noticeable. And further, if the calculation is deployed on edge devices, the calculation may take up to the scale of 1s, which will dramatically influence the feedback experience. An unprocessed delayed feedback decision can create a completely usability breakdown easily. This latency is one variable while the solution is working, a constrain in the solution, and a problem to tackle using the appropriate strategy.

3.4.2 Strategy for interpreting the instructions

A feedback system receives decisions on the next move and translate the decision into physical feedback. And there is one set of strategies during the process. The strategy is more crucial while the latency of the decision is taken into concern. In this work, the feedback system will not only get information from the decision-making process, the real-time locally information will also be taken into concern. By taking advantage of that additional information, the feedback system may be able to reduce the influence of the system latency and provide a more seamless experience. Therefore, I need to find out how to merge all that information and present the actual feedback. The strategy is one crucial variable in the system.

3.4.3 Time, Density and Intensity

Time – frequency of the feedback adjustments. (Typically, not the vibration frequency)

Density – density of the vibration points.

Intensity – intensity of the vibration.

Those three variables are more quantized ones in this study. And varies combinations of those variables and different strategies represents different feedback systems. And the goal for clarify those variables is to find the optimal combination. The optimal combination should be the cognitive upper limitation of human. To find out those limitations, I need to have the hardware that can provide feedback that is obviously above the human limitation and a set of metrics to evaluate that.

3.5 Hardware above human limitation

I propose a hardware solution that can provide real-time adjustable vibration feedback on shoulders. The vibration feedback solutions in prior researches suffered from the limited information. To provide more information within the same physical form, new dimensions of information need to be extended. Fortunately, there is still room to do that. The origin of the information limitation comes from the vibration actuator. The current solutions are mainly using eccentric motors to generate vibration. The state of the motor is limited to on and off. The vibration intensity is simulated by applying PWM (pulse width modulation) from the driving circuit. The resolution is low, and the adjustment can not be done in real time due to the initial of the motor.

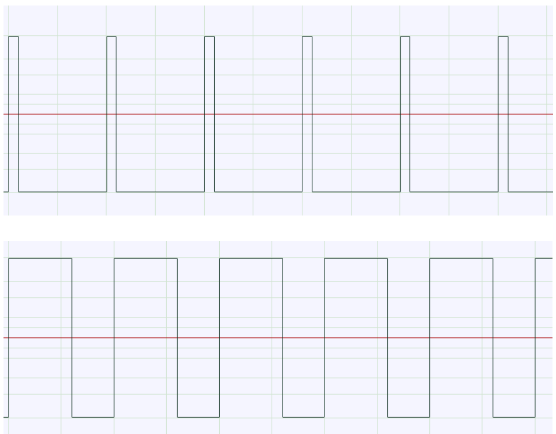

Fig 1 Ilustration of PWM vibration intencity control signal.

By applying linear vibration actuators and audio amplifier driver circuit, the real vibration intensity can be added. One typical application of the linear vibration actuators is Apple’s “Haptic Engine” embedded in their cellphones and touchpads. The linear vibration actuators are fundamentally different from the eccentric motors. The structure is closer to speakers, which enabled the high resolution and high response speed.

Theoretically, the minimum adjustable duration can be reduced to only one cycle of vibration (~6ms).

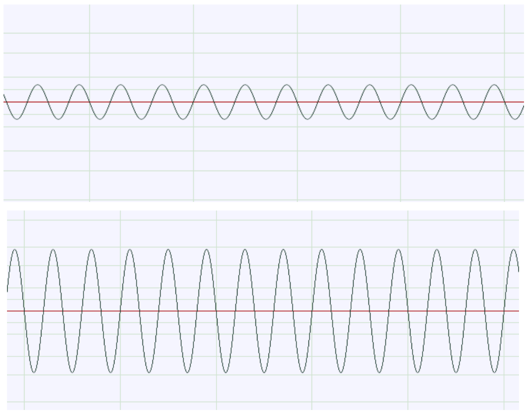

Fig 2 Illustration of analog amplitude vibration intensity control signal.

Only high response speed cannot form a seamless experience. Since the decision making may not happen as fast as the feedback adjustment cycle. Therefore, the idea of closed loop feedback will be applied to fill in the gap. Closed loop means tracking the user's orientation in real time to monitor how well the user response to the previous instruction. The feedback system will adjust the feedback at a higher frequency according to that instead of the low frequency instructions.

This hardware solution will be able to provide the desired above human cognition feedback, in order to provide a tool to find out that limitation. The sensor based closed loop design also provided the extra information that is needed for making the strategy.

3.6 Metrics[1] for finding out the limitation

Those metrics need to provide objective criterions for evaluating how is the user responding to the feedback system.

In the problem statement section, the indoor open space navigation problem is split into two parts. Rotating to the right orientation and going straight toward the destination. And for the purpose of an objective evaluation, the orientation task along will be able to provide the needed information. Orientation task can represent most of the complex tasks including turning, avoiding the obstacle or tracking a certain route.

The key in this task is to correctly record the actual orientation of the user in order to evaluate how the system and the user performs. The best way to do that is to take advantage of the gesture tracking system used in VR. The actual angle can be tracked accurately using HTC Vive. Its sensors are reported to have a static orientation standard deviation smaller than 0.01°[12]. Since the feedback device will be moving with user's truck, the Vive headset or controller should also be locked with the user's truck instead of head or hands. This will correctly represent the feedback system's performance.

3.6.1 Steps

1) The user should be blindfolded. The major concern here is that the participant should not get the help from their vision. There will be participants without visual impairments entering this test. And for the actual users, the majority of VIP still have different level of remaining vision. Since the test is about the feedback system only, they should not get any help from that too.

2) The target final angle will be generated randomly around several pre-set base values. The random is to prevent participants from learning the rotating. The learning of our system is allowed and will be tested as a metric. However, the user should not remember what angle to turn to. The base values are set to ensure the results can be compared between different participants and under different testing conditions.

3) The target will be an angle-time curve to simulate the real use case. Since the macro world is continuous.

4) Once the test started, the vibration feedback will start. The instructions will be based on the angle value collected by HTC Vive. The frequency of the instruction will be adjustable to simulate different decision-making solutions.

5) The user should follow the feedback and try to rotate to targeted angle. One the user stops adjusting according to the feedback, the task is considered done. The system will stop recording the orientation data. And one round of test is done.

3.6.2 Metrics

1) The standard deviation between the target angle-time line and the real one.

2) Actual time taken to complete the task.

3) Final orientation accuracy.

5) Overreact of the user from the recorded data.

3.7 Build the feedback system

From the prior steps, the limitation of the human is already studied. And the set of optimal variables are selected. It is time to build the feedback system following the guide of those findings. Building the feedback system is as easy as applying the optimal variables into the cognitive evaluation hardware. And the system will be ready for performance evaluation.

3.8 Metrics[2] for comparison

To evaluate the performance of the overall feedback system, there need to be a set of common tasks and metrics that can be applied to most of the methods in VIP indoor navigation feedback problem space. This set of metrics for the final evaluation will be a collaborated work between me, two researchers at Tsinghua working on the evaluation metrics topic and other two GIX students having thesis topics under the same macro VIP navigation feedback problem space. Overall, the task should be a simulated indoor navigation task within a relatively simple scenario. The simplicity is required because their will not be a reliable sensing and decision-making parts to compose the complete navigation system. Those will be simulated using an indoor positioning system and a simulated route on in a large plane space. The other reason is that the audio feedback is not present in every feedback solution. Therefore, complex scenarios should be avoided in this evaluation.

Like the first evaluation task, the key factor here is still how to record the ground truth of user position. According to the reply from the official form, HTC Vive is recommended to work within the range of 5 meters. This length is a little bit short for evaluating the “go straight” task. Therefore, another method should be used in this task to record the position data. Potential candidates are indoor positioning technologies and computer vision solution. The accuracy of radio based large-scale indoor navigation is low (noise can be decameter level.). Such methods include Bluetooth, Wi-Fi and UWB. Thus, a customized computer vision solution would be better for its higher accuracy. And it is relatively easier to implement. As for the orientation data, it may be recorded with the sensor built in the system. This may lead to a lower accuracy, but this is not the major concern in this task.

3.8.1 Steps

1) The participant will be blindfolded for the same reason.

2) The simulated route should have a certain number of turns, straight lines and

curves.

3) Vibrations with schematic will be used to provide not only rotation information, but also start / stop information.

4) There will be a physical object at the destination. Once the user touches the object, one round of test is done.

3.8.2 Metrics

1) Time of the task.

2) Standard deviation from the targeting route.

3) User satisfaction.

4) User confidence.

5) Learning curve.

Chapter 4 Research Plan and Schedule

Table 3 Research plan and schedule

Time		Task
UW	Quarter 4	Further investigation.
		Build the haptic feedback prototype.
		Design the haptic feedback strategies.
		Design the tasks in metrics 1 & 2
	Break (1 month)	Build the HTC Vive test platform for metrics 1.
		Find the optimal combination with None-VIP participants.
		Build the CV platform for metrics 2.
		Performance evaluation with None-VIP participants.
	Quarter 5	Iterate.
Tsinghua		Rebuild the evaluation platforms.
		Fine tune the optimal combination with VIP participants.
		Performance evaluation with VIP participants.
		Paper writing.

Chapter 5 Expected Contributions and Outcomes

1) Contribution on human factor study

The cognitive limitation for providing shoulder vibration feedback on VIP navigation. This study can guide the future work following the same approach.

2) Contribution on technology

A high definition vibration feedback platform. This platform can be implemented into all vibration feedback systems currently using eccentric motors to improve the performance.

3) Contribution on method

The performance improvement from the feedback hardware and the strategy design.

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