Vibrotactile Wristband for Warning and Guiding in Automated Vehicles

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ABSTRACT

In this paper, we introduce a vibrotactile wristband for warning and guiding the driver based on the road condition in automated vehicles. The vibrotactile wristband can receive the command from the host computer in the vehicles via Bluetooth and generate the corresponding vibration patterns with six vibration motors. 3 vibration patterns are designed to guide the driver to the right direction in the manual driving state and 8 vibration patterns are designed to warn the driver about the problems which the driving support system can't solve in the automatic driving state. Based on tactile illusions, we convert the graphical markers into the vibration patterns to reduce the driver's memory burden and improve the accuracy of recognizing the patterns. In order to evaluate the performance of the vibrotactile wristband, a virtual driving environment is developed and the subject can experience the vibration patterns when he/she drives the virtual vehicle.

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KEYWORDS
Vibrotactile feedback; driving support; vibration pattern; wristband; vibration phantom

1. INTRODUCTION

It is likely that within a decade or two highly automated driving will be introduced on public roads [10]. Its driver doesn't need to keep his/her hands/feet on the steering wheel/pedals and has the chance to take the eyes off the road when he/she is out of the control loop [7]. However, when the automated driving system reaches its functional limit, it has to send a take-over request and convert the control generator from the automation to the driver. The driving support system also needs to guide or warn the driver when he/she is in the control loop [6].
In both cases, a feedback device which is integrated into the vehicle system is required to warn the driver to get back into the control loop or guide the driver in the right direction. When the system uses a visual feedback device, the driver has to look at the visual feedback device. The auditory feedback may be suppressed by the surrounding noises. Compared with these two feedback approaches, the haptic feedback device can supply a personal, efficient feedback that can attract the driver's attention without interfering with non-driving task.
In this paper, we introduced a vibrotactile wristband as the haptic feedback device for automated vehicles to guide and warn the driver as shown in Figure 1. The control system of the wristband can receive the commands from the host computer and drive the motors attached on the wristband. The six motors on the wristband can generate various vibration patterns. Based on the tactile illusions, 11 vibration patterns are designed according to the corresponding graphical markers related to the road conditions.

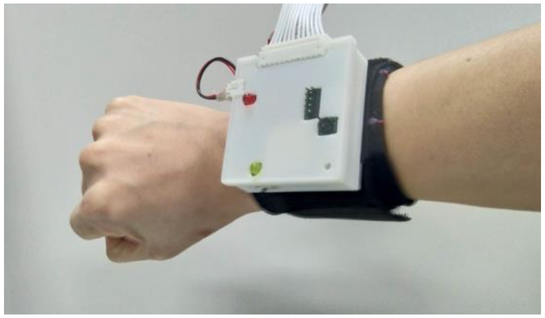

Figure 1: vibrotactile wristband for automated vehicles.

2. RELATED WORKS

Recently, haptic displays have been introduced into the automotive system, and vibration which can be applied to multiple regions of driver's body is one of the most feedback approach among displays. In a vibration feedback device, little power is consumed and the actuator is small enough to be equipped anywhere, such as the seat [4], the steering wheel [9] or the waist belt. Compared with these works, the vibrotactile wristband meets the requirement of freedom of action in the vehicle with the attribute of being wearable and light.
Many vibration feedback devices worn on the wrist are designed as the space indicator to guide people in the movement task. Anke et al. developed a vibration bracelet to guide the visual impaired people to walk to the destination on the street [2]. Jose et al used six vibration motors to generate the phantom vibration feeling to navigate the user to his/her destination [8]. In these system, few vibration patterns are developed and only the information of direction will be transmitted to the user. Different from these works, our feedback device supplies more information to the user with various vibration patterns encoded in two dimensions of space and time.

3. HARDWARE ARCHITECTURE

This section describes the detail of the hardware architecture which contains actuators, the control circuit, the battery and the band with the shell.

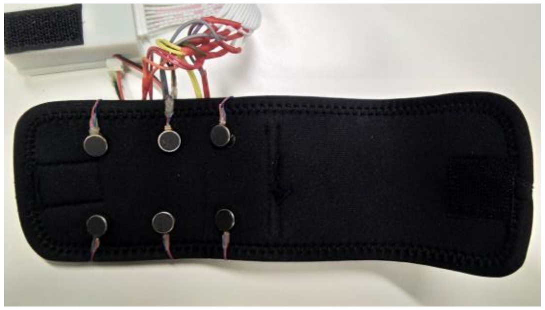

Figure 2: Flat type vibration motors attached on a sport wristband.

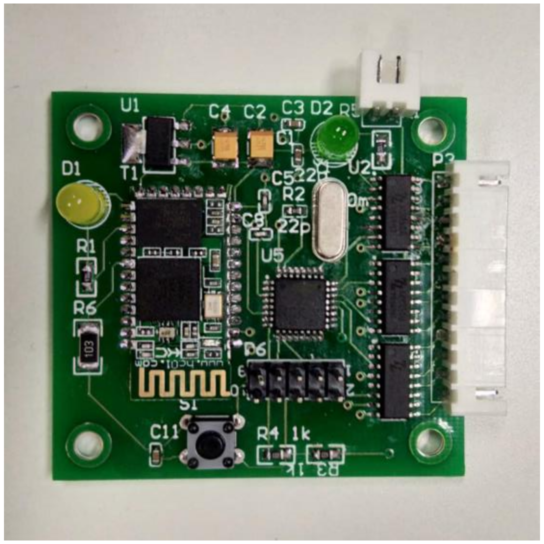

Figure 3: Control circuit board.

3.1 Actuators

Flat type vibration motors are chosen as actuators to generate vibrotactile stimuli as shown in Figure 2. The motor is encapsulated in a flat cylindrical housing whose diameter and thickness are respectively 10mm and 2mm. The motor's operating voltage ranges from 2.5 to 4 VDC. At the rated voltage of 3V, the measurement current is 90mA and the rotation speed is 11000±2000 RPM. The magnitude of the motor's vibration is linearly related to the rotational frequency which is proportional to the input voltage, so we can adjust the output magnitude of the vibration by controlling the input voltage. The maximum operating voltage is set as the rated voltage of 3V in order to prevent motors from burning down.

3.2 Control circuit and power

We developed a control circuit board whose width and length are 50mm and 54mm respectively to control the wristband system as shown in Figure 3. The circuit board consists of MCU circuit, communication circuit and motor driver circuit. C8051F320 used in the control circuit is a fully integrated mixed-signal System-on-a-Chip MCU which includes 16k bytes of on-chip FLASH memory and 25 I/O port pins. Bluetooth is chosen as the wireless communication module connecting to the host computer on the vehicle. The Bluetooth module sends the command received from the host computer to the MCU module over RS232. The driver circuit consists of three power amplifiers MX1508 in order to drive six vibration motors. These amplifiers transform the PWM digit signal from the MCU to the analog voltage signal. To increase the space of the driver's movement, a lithium ion battery is used as the power source whose output voltage is 3 VDC and rated output current is 2A. The battery capacity of 2000mAh is large enough to drive the six motors continuously for 1hour. The wristband can be used for longer than 1hour during a real drive since it does not vibrate all the time while driving. In consideration that the input voltage of MCU is 5V, we designed an electric transformer circuit from 3V to 5V for the battery.

3.3 Shell and band

The six vibration motors are attached to a sport wristband and arranged at three columns and two rows as shown in Figure 2. The motors' spatial positions are fixed completely on the band, and the distance between two adjacent motors' center is 35mm. Because the perimeter of user's arms is different, the wristband can be kept tied to users' arm by an elastic belt whose length can be changed based on the requirement.

The circuit board and the battery with its transformation circuit are fixed in a 3D-printed shell. The material of the shell is photosensitive resin and the shell's size is 55m*58mm*22mm. The circuit board is connected to the motors with a set of wires across a rectangle hole on the shell. The shell can be pasted up on the wristband by hook&loop taps.

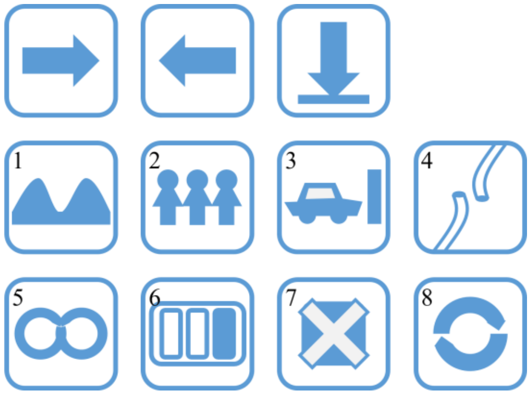

Figure 4: Graphical markers designed for vibration pattern. The markers in the first row belong to the guiding mode whereas those in the second and third rows belong to the warning mode. The implication of these makers is shown in Table 1.

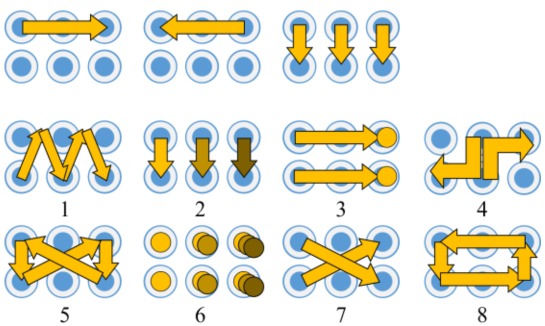

Figure 5: Vibration patterns for guiding or warning the driver. The patterns in the first row belong to the guiding mode whereas those in the second and third rows belong to the warning mode. The signs with different colours represent different vibration sections while the lighter colour means that the section is at the forefront.

4. WORKING PROCESS

Apparent tactile motion is also known as phi-phenomena that when two vibrotactile stimuli were placed on the skin in close proximity and their actuation times overlapped, the user would not perceive two actuators, but rather a single actuator moving between them [3].

Phantom tactile sensation is also known as the funneling illusion that a simultaneous stimulation of two vibrotactile actuators placed in close proximity would create an illusory vibrating actuator located between the real actuators [1].

Based on these two phenomena, Ali Israr and Ivan Poupyrev presented the tactile brush algorithm which can provide a solution for creating two-dimensional, high-resolution, continuous moving sensations on the surface of the skin [5].

All of the vibration patterns of the proposed system are designed based on the tactile brush algorithm in order to reduce the memory burden of the user and enhance the connection between the visual sensing and haptic sensing.

4.1 Vibration patterns

In order to meet different driving states, two command modes are designed, i.e. guiding mode and warning mode. In the guiding mode, the host computer monitors the driver's state and the road condition, and three commands will be sent to the wristband system based on the navigation system and the vehicle's state. These three commands are respectively "turn left", "turn right" and "brake" as shown in Figure 5. To spend lesser time to transmit these messages, the duration of vibration in the guiding mode is set to be around 300ms. Single row of motors will vibrate in order to save power because these commands will be transmitted frequently.

To inform the drivers who is out of control loop that the vehicle meets the complex situation, the host computer recognizes the specific situation and classifies it as 8 commands. In this situation, we designed 8 vibration patterns corresponding to these commands in the warning mode as shown in Figure 5.

Because there is no prior experience of these vibration pattern for the driver, it's very hard for him/her to memorize these pattern directly. The relative graphical markers shown in Figure 4 are designed for these road commands. It will be easier for the users to recognize and memorize these markers with lesser training as these markers are related to the real situation. Based on these graphical markers, we designed the corresponding vibration patterns whose vibration feeling's trajectory is very similar to the lines in the markers.

The commands and the vibration pattern can be linked by the graphical markers as a perceptive bridge, which led to the implications of vibration patterns that are easier to remember for the user. After remembering the patterns, drivers can learn the condition immediately by feeling the vibration patterns. In the warning mode, the duration of each vibration sequence is around 800ms.

Table 1: The implication of the corresponding markers and vibration patterns

Index	*Implication of the markers or vibration patterns*
1	The vehicle is running on a bumpy road.
2	Pedestrian is walking in the way.
3	The vehicle is facing a complex obstacle which is hard to deal with.
4	The vehicle can't connect to the internet.
5	The navigation function can't be used cause of some problem.
6	The power is low.
7	The vibration wristband doesn't work.
8	The vehicle is meeting some unknown problem.

4.2 Signal flow

The wristband can receive the command codes and actuate the motors after the host computer judges the road condition and sends the command codes to the wristband via Bluetooth. The codes from the host computer involves the index of the vibration pattern and the intensity of the vibration. The memory of the MCU stores all the vibration sequences which can match those indexes. These vibration sequences are represented by several two-dimension arrays whose every row consists of the intensity of six motors' vibration and the duration of one part of the whole vibration sequence. All the rows of one array will be executed one by one and the vibration will be actuated based on the content generating the corresponding vibration pattern. The MCU will control the duty cycle of the square digital output signal to adjust the intensity of the motors' vibration. When the host computer recognizes the special states, it will deal with the problem by stopping the car and send the take-over request to the driver as the same time to ensure the driver's safety.

5. VIRTUAL DRIVING ENVIRONMENT

To evaluate the performance of our vibrotactile wristband, we developed a virtual driving environment as shown in Figure 6. The environment is established with Unity3D and can run on PC platform controlled by mouse and keyboard. We arranged the environment based on the real street scene and added a highway and some buildings into it. To test the performance of the wristband, obstacles are set in the highway, such as pedestrians and vehicles. To realize the state of being out of control loop, the vehicle possesses the navigation and automatic driving function. In the navigation mode, the vehicle can keep running on the right way to the destination. In the virtual environment, some relative responses are generated at the specific position or under the specific condition such as the power is low.
In the manual driving mode, the commands in the guiding mode will be sent based on the navigation direction. The user can encounter all the conditions and experience all the vibration patterns, and they can evaluate the performance of the wristband based on the subjective feeling.

Figure 6: Virtual driving environment

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6. CONCLUSION AND FUTURE WORK

This paper introduces the vibrotactile wristband that can warn and guide drives in automated vehicles. The vibrotactile wristband can receive the commands sent from the host computer in driving support system, and convert the command to the vibration patterns applied on the wrist of the driver. Based on tactile illusions, 3 vibration patterns for guiding mode and 8 vibration patterns for warning mode are designed according to the corresponding graphical markers.
In the future, we will design an experiment to evaluate the performance of the vibrotactile wristband. The reaction time of recognition the vibration patterns and the duration of training to remember the patterns will be measured in the experiment.

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