Haptic Collar – Vibrotactile Feedback around the Neck for Guidance Applications

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Figure 1: The haptic collar prototype worn by users during the experimental setups.

ABSTRACT

In this paper, we present a Haptic Collar prototype, a neck worn band with vibrotactile actuators for eyes-free haptic navigation. We evaluate the system for guidance applications on over 11 users, analyzing 4 different tactile patterns regarding comfort and ease of understanding as well as the number of actuators to encode 8 directions (4, 6 and 8). Overall, users can recognize the directional signs well (up to 95 % recognition rates for over 528 triggers). We also present a use case applying our prototype for a haptic navigation walk.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**.

KEYWORDS

Haptic Feedback, Vibrotactile Actuators, Collar, Neck, Navigation, Haptics, Sensitivity

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1 INTRODUCTION

Researchers in the human augmentation field get more and more interested in the sense of touch to extend our perception. Still compared to visual and auditory augmentation technologies, haptic feedback is not as explored.

Many works focus on augmenting the hands, as apparently, the hands have high sensitivity and resolution related to haptic feedback. Regarding guidance and navigation applications, head and vest devices also seem popular. However, as far as we know, nobody evaluated haptic feedback around the neck for guidance applications.

In this paper, we present Haptic Collar, a neck worn band with off-the-shelf vibrotactile actuators for guidance applications. The contributions of our work are as follows: (1) we present a prototype

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of a haptic collar wearable in everyday situations, providing at least feedback for 8 directions, (2) we evaluate several haptic patterns related to comfort level and direction comprehension, (3) as well as the number of actuators (4,6,8) best used to encode 8 directions over 11 users (with over 95% accuracy), (4) we also present a guidance use case in which the users use the system to navigate following the vibrotactile feedback.

2 RELATED WORK

Much related research focuses on tactile feedback on the hand for notifications, continuous information or general eyes free feedback [4, 10, 14]. The works here usually augment existing tools from smartphones to scalpels or other specific devices used for dedicated applications, or they augment the hand directly using glove or ring prototypes [2, 10].

For guidance and navigation applications many researchers use head mounted or belt/vest devices. Rantala et al. present a headband with vibrotactile feedback for cueing in virtual reality applications [13]. Berning et al. translate ultrasonic distance information to pressure on the head as well [3]. Špakov et al. found that stimulation on the neck and head were as efficient in cuing users as stimulation on the back even with smaller amplitude levels using a prototype based on two separate headbands worn on forehead and neck [15]. This method is similar to the presented one in regards of how directions were translated into vibrotactile feedback, however, the Haptic Collar does not require separate devices for different directions, but combines all directions in one neck-worn prototype. Harvie et al. compared several tactile acuity measurement methods on the neck used in musculoskeletal practice and introduced a Imprint Tactile Training Device containing 12 vibrotactile nodes that deliver vibration stimuli to the neck, whose locations have to be identified by the user [6]. This localization test only focuses on a square area on the back of the neck, not including the whole cervical area. Other research focuses on improving spatial awareness and improving 3D guidance in VR using haptic feedback on the head [5, 8]. Considering guidance applications, Niforatos et al. augment the peripheral vision of skiers using vibrotactile actuators [12]. Vest and Torso based feedback is also widespread for guidance, navigation, and immersion applications [1, 7, 9, 11]. So far, we are not aware of other research work exploring several vibrotactile actuators for navigation/guidance applications on the neck.

3 APPROACH AND PROTOTYPE

To find out whether haptic feedback on the neck in the form of vibration can be successfully utilized to navigate users without visual input, e.g., looking at a map or a phone, we built a prototype that included off-the-shelf components.

Our focus was to have an easy to make and ready solution for other researchers to use. Besides, we picked the neck as it is easily accessible (users can comfortably wear a device there).

The prototype consists of a velvet collar with Velcro tape attached to its inner side (see fig. 2). This also serves as the closure of the velvet ribbon and makes it adjustable to the test subject's neck size. 8 vibration modules attached with Velcro tape can be flexibly affixed to the collar according to the neck size. For the prototype, we are

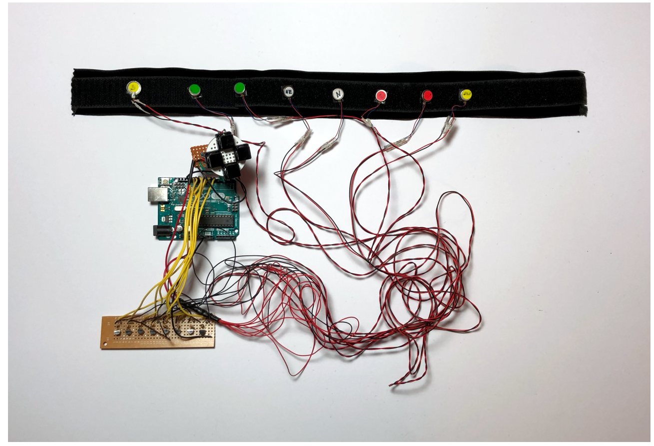

Figure 2: The Haptic Collar Prototype used for the experimental setups

using the eccentric rotating mass actuators (Shicoh C1034, Japan). The actuators are driven with a PN2222 transistor. The vibration modules are powered and controlled by the Arduino UNO board as shown in fig 2, and can be actuated individually. For tests, we used hardware buttons to trigger the individual vibration patterns.

4 EXPERIMENTAL SETUPS

Subsequently, we describe the two experimental setups we conducted with the Haptic Collar prototype: First, a "Pattern Study" that focuses on qualitative feedback on how easy and understandable the vibration patterns are. Second, a "Number of Actuators Study" to evaluate direction encoding and the sensitivity of the participants using 4, 6 and 8 actuators around the neck.

The proposed system was tested with a population of n = 11, five males and six females. The age range was 24 to 34 (mean 28.09, SD 3.30), 7 different cultural backgrounds. Every volunteer has given written consent and was not rewarded for the participation in the experiment. They all reported to use visual-based mapping apps for navigation, with Google Maps being used by 100% of the test population. All but 2 of them were familiar with the concept of haptic feedback (n = 6) or had an idea of what it is (n = 3).

4.1 Pattern Study

The collar was put on the participant's neck, and the vibration modules were adjusted to the participant's neck size with one vibration module on each straight axis [1] and one actuator on each diagonal axis in the middle between the straight axes. The subject then was exposed to two clockwise rounds of the same vibration pattern and then asked questions about the comfort of the vibration pattern and the clearness of the direction. Then the next vibration pattern was introduced. The same questions were asked for each pattern and in the end questions about the overall comfort and clearness of direction were stated. The four vibration patterns tested were in

[1] In this experiment the straight axes are Front (F), Right (R), Back (B), Left (L) and the diagonal axes are Front Right (FR), Back Right (BR), Back Left (BL), Front Right (FR), and Front Left (FL).

this order: single short: a short vibrations of 200ms; multiple long: two vibrations of 250ms; multiple short: five vibrations of 50ms each; single long: one long vibration of 500ms.

4.2 Number of Actuators Study

To find out whether 4, 6, or 8 motors are needed for users to be able to accurately point out 8 different direction of the vibrations on their neck, three different setups were designed using 4, 6, and 8 vibration motors respectively (see fig. 3). For the 4 motor setup, vibration modules were used on the perpendicular axes (F, L, R, B) and vibrating two motors at the same time was used to indicate diagonal directions, e.g., the F and R motor vibrating at the same time indicated a FR direction. Each direction is triggered twice during each setup to eliminate guessing alone as the reason for successfully identifying the direction. The order of the 16 directions in total was counterbalanced using the Latin Square model. The experimenter triggered the directions manually by pressing the buttons on the device and a serial console printout confirmed the direction the experimenter indicated. For the 6 motor setup, a vibration of the FL and FR motors indicated a forward direction and BL and BR a backward direction. The 8 motor setup does not require compromising in the directions since every vibration module is assigned to one direction. The hypothesis is therefore that this setup is the one that participants will be most comfortable with. In-between the different setups, the participant was asked questions about the comfort and the comprehension of the direction of the vibrations as well as a qualitative, subjective evaluation.

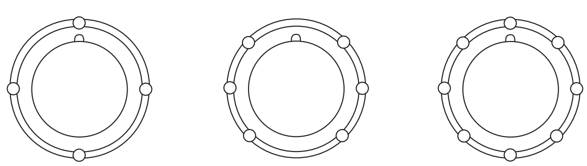

Figure 3: Schematic view of the arrangement of the 4 (left), 6 (center) and 8 (right) motor setup

5 RESULTS

Pattern Study The qualitative feedback survey in-between the setups focused mainly on the level of comfort and the direction comprehension of the vibration. Regarding comfort, the means of the different vibration patterns on a scale from 1 to 10 are as follows: single short = 6,00, multiple long = 5.36, multiple short = 5.90, single long = 5.50. The means regarding clearness of direction were: single short = 8.82, multiple long: 8.73, multiple short = 8.09, single long = 8.18. According to the participants, the shorter vibrations were generally regarded more comfortable as shorter vibrations did not feel too strong, but rather like a "nudge" towards the right direction. The single long vibration pattern was perceived as more intruding and therefore more uncomfortable. One participant mentioned that the long duration of the single long vibration pattern made the vibration disperse along the collar, so the location of the vibration source was harder to determine. While repetition of the vibration was appreciated since it made it easier for users to verify that there was a vibration and also its location, the short version caused a sense of alarming urgency for some. The short single vibration pattern ranked first both in clearness and comfort on the linear scale and shared the top rank in comfort with the multiple short pattern when asked for the most comfortable pattern. However, in the qualitative feedback given after all patterns were introduced, the single short pattern was seen as the most unclear in terms of direction, which stands in contrast to what the participants replied in the linear scale questions in the survey in-between the different vibration patterns. This might be explained due to ordering effect. It can be summarized that although short vibrations seem to be more comfortable, a repetition is helpful for input and location verification.

Number of Actuators Study The directions of the vibration indicated by the participant were compared to the actual direction that was triggered to find out how reliably the participant could identify the different directions and to find out differences in the number of errors for each subject in-between the different setups.

The recognition rates based on the responses of the participants are as follows, for 4 motors 72 % correctly identified, for 6 motors 81% and 8 motors 95%. The detailed confusion matrices can be found in fig. 4. 8 motors work best in the trials. However, also the 4 motor setup has only confusions between the adjacent directions. It seems the diagonal directions are the most difficult for users to point out. Also, the qualitative feedback indicates that users preferred the 8 motor setup in terms of direction comprehension (mean = 8.00 as opposed to 6.45 (4 motors) and 6.09 (6 motors) and comfort level (mean = 7.63 as opposed to 6.72 (4 motors) and 6.91 (6 motors).

6 USE CASE: HAPTIC NAVIGATION

The test subjects were asked to go on a walk outside together with the experimenter. Each subject started from the same starting location toward the same final location. They were asked to follow the direction of vibration and were supposed to go based on the haptic feedback they received. When an error occurred, the test subjects were not notified of it, but guided along the set trail. The specific route that the test subjects were supposed to walk can be seen in fig. 5 and was chosen since it includes 7 out of all 8 vibration directions in a short and easily accessible area. The test subjects were engaged in casual conversation with the experimenter to make the setting as natural as possible to see how natural and intuitive the haptic navigation process could work in a real life situation. After the test the participants answered a survey about the walking experience that the experimenter filled in for them.

The haptic navigated walk took around 15 minutes per participant. The FL direction had by far the highest error with a total of 8 out of 20 occasions, which is an error rate of 0.4 or 40%. One reason for this high error rate could be that missing the second FL turn automatically results in missing the BL turn. From the survey, it can be derived that directions were fairly easy to understand (mean = 7.36) and quite sure about being on the right track (mean = 7.36). The overall feedback was positive, one participant mentioned that

perceived as:	F	FR	R	BR	B	BL	L	FL
F	21	0	0	0	0	0	0	1
FR	3	9	10	0	0	0	0	0
R	0	3	16	3	0	0	0	0
BR	0	0	1	11	10	0	0	0
B	0	0	0	0	21	1	0	0
BL	0	0	0	0	4	11	5	1
L	0	0	0	0	0	2	19	1
FL	1	0	0	0	0	0	3	19

perceived as:	F	FR	R	BR	B	BL	L	FL
F	12	1	0	0	0	0	0	9
FR	0	19	3	0	0	0	0	0
R	0	4	18	0	0	0	0	0
BR	0	0	3	19	0	0	0	0
B	0	0	0	0	21	1	0	0
BL	0	0	0	0	3	19	0	0
L	0	0	0	0	0	0	20	3
FL	2	0	0	0	0	0	3	19

perceived as:	F	FR	R	BR	B	BL	L	FL
F	22	0	0	0	0	0	0	0
FR	0	22	0	0	0	0	0	0
R	0	0	22	0	0	0	0	0
BR	0	0	1	11	10	0	0	0
B	0	0	0	0	21	1	0	0
BL	0	0	0	0	4	11	5	1
L	0	0	0	0	0	2	19	1
FL	1	0	0	0	0	0	3	19

Figure 4: Confusion matrices for direction recognition (left: 4 motors, middle: 6, right: 8. Directions: Front (F), Front Right (FR), Right (R), Back Right (BR), Back (B), Back Left (BL), Left (L), and Front Left (FL) respectively.

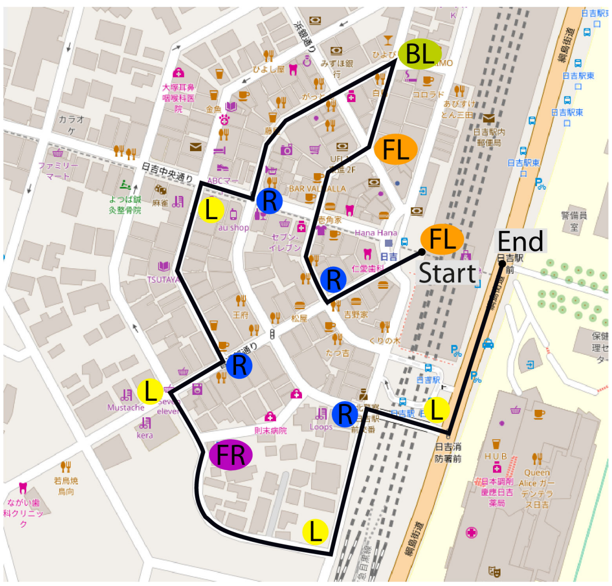

Figure 5: Original Route for the Haptically Navigated Walk

they were surprised how little effort it took to process so they could "intuitively" follow the directions while talking to someone, which made it feel very "natural."

7 CONCLUSION AND FUTURE WORK

We present Haptic Collar, a system exploring vibrotactile feedback on the neck for guidance applications. Overall, the system works well (73 - 95% accuracy) with short vibration patterns. 8 vibration motors seem to work best for the applications, which confirms the hypothesis (yet 4 and 6 also performed at acceptable level, disregarding the diagonal directions). In the future, we want to extend the work trying different vibration patterns for guidance and also explore other application scenarios for the system (e.g. immersion effects incorporating audio with haptic feedback) as well as explore different materials and assembly techniques to improve comfort.

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