Exploring Distance Encodings with a Tactile Display to Convey Turn by Turn Information in Automobiles

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ABSTRACT

Visual and auditory displays successfully complement each other presenting information in car navigation systems. However, they distract the visual and auditory attention of the driver, which is needed in many primary driving tasks, such as maneuvering the car or observing the traffic. Tactile interfaces can form an alternative way to display spatial information. The way of how exactly information should be presented in a vibro-tactile way is explored rarely. In this paper we investigate three different designs of vibro-tactile stimulation to convey distance information to the driver using a tactile waist belt. We explore the tactile parameters intensity, rhythm, duration, and body location for encoding the distance information. We conduct a comparative experiment on a real navigation scenario in an urban environment to evaluate our designs.

In our study we discovered that rhythm and duration are suitable parameters to generate tactile stimulation for encoding distance information. In this way the driver perceives countable vibro-tactile pulses, which indicate the distance in turn by turn instructions. The approach is found be simple way of encoding complex navigational information.

ACM Classification Keywords
H.5.2 User Interfaces: Haptic I/O; 1.3.6 Methodology and Techniques: Interaction techniques

General Terms
Human Factors, Experimentation

Author Keywords
Car navigation system, Tactile interface

INTRODUCTION AND MOTIVATION

The activity of driving is multi-tasking and complex [12]. Vehicles are equipped with a number of distinct information systems to support the driver. A car navigation system is one of the promoted and preferred information systems for cars. Visual and auditory displays in the present car navigation systems are successful to provide spatial information. However, the car navigation system increases a demand of the driver’s visual and acoustic attention while driving and are subject to distract the driver. The visual attention of the driver is essential in the primary task of driving, which is for example steering the car, using brakes and controls as well as observing the traffic. Pauzie and Marin [10] investigated that aging drivers spent 6.3% and young drivers spent 3.5% of their driving time glancing at the screen. Auditory displays on the other hand are challenging in a noisy environment. The driver performs a multiple number of primary and secondary tasks on visual and auditory displays that can impose mental workload [4] and distraction [12], which is harmful for safety of driving.

A tactile display can be used as an alternative interface for the car navigation system to reduce the mental workload and the distraction, following the Multiple Resource Theory (MRT) [21]. Two important parameters of the turn by turn navigation are direction and distance [2, 19]. In previous studies car simulators have been used to evaluate the vibro-tactile distance encoding. However, the investigation of the precise approach of vibro-tactile distance presentation in a real environment is missing. We investigated a number of the encodings based on rhythm, intensity and duration to discover an appropriate approach for the vibro-tactile distance encoding. We evaluated three vibro-tactile distance encodings in an experiment: (1) Only rhythm based distance encoding (2) Rhythm and intensity based distance encoding (3) Rhythm and duration based distance encoding. In our study, we focused on comparing different methods of conveying the distance with the vibro-tactile feedback in real urban environments. The study shows success of duration in combination with rhythm based distance encoding in the car navigation systems.

In the remainder of this paper, Section 2 introduces the reader with the state-of-the-art tactile interfaces and related approaches of the vibro-tactile distance and direction encoding in automobiles. The design space and the vibro-tactile distance encodings are described in Section 3. The experiment details are presented in Section 4. In Section 5 we report the find-
ings. In Section 6 we discuss the answers to our research question and further findings. We close the paper with a conclusion in Section 7.

RELATED WORK

Previous research has shown that the tactile displays were effectively used to provide navigation aids to the pedestrians and blind users. McDaniel et al. [9] present a scheme for using tactile displays to convey intimate, personal, social interpersonal distances to blind users. ActiveBelt [16] consists of a number of vibration components integrated into a belt or a vest. The vibration components are equally distributed around the person's body and activated for showing him a direction. Tactile Wayfinder [5] was evaluated for the task of pedestrian route guidance. The tactile Wayfinder supported the pedestrian in orientation, choice of route, keeping track, and recognition of destination. PeTaNa [20] a torso based wearable system was evaluated to present direction and distance information to soldiers in the field. The direction information was presented on the respective location of torso of the soldier. Distance was coded with the temporal rhythm on the vibration. van Erp et al. [19] investigated different distance encoding schemes with pedestrian participants. The vibration rhythm was used to code the distance and the body location was used to code the direction. An additional experiment investigated usefulness of tactile display with a helicopter and a fast boat. Straub et al. [14] used a vibro-tactile waist belt to encode distance for the pedestrian. They used four distance encodings based on the parameters of intensity, frequency, position (which tactor), and patterns. Pielot et al. [11] presented a position and spatial distance of several people with the help a tactile torso based display in fast paced 3D game. The results showed that the location of the team members can be effectively processed with the help of the tactile display in high cognitive demand. The team showed a better team play and higher situation awareness. The findings of the previous studies encourage the fact that it is possible to encode distance with tactile displays. The effectiveness of the tactile display for presenting direction and distance information to blind and pedestrians motivate the idea to discover the approach to code distance in vibrotactile signals in car navigation systems.

Furthermore, the tactile interface is effectively used in Advanced Driver Assistance Systems on commercial scale e.g. in Citroen1 and Audi2 in the seat and steering wheel, respectively. Similarly, the previous studies investigated the feasibility of the tactile channel in vehicle information systems e.g. in car navigation systems. A vibro-tactile seat is developed with the characteristics of a matrix with 6 x 6 elements with interaction area of a 430 by 430 mm with dynamically modifying haptic feedback based on the driving sitting posture [13]. A prototype steering wheel [7] is integrated with six tactile actuators. The steering wheel is used to display the direction in a car simulator. The best driving performance is attained by combining tactile display with a visual display or an auditory display. A seat fitted with 24 vibrators in an 8 x 8 matrix [6] is used to evaluate the ability of drivers to distinguish up to eight different directions. The distance information is presented by van Erp and van Veen [17] with vibrocon (vibro-tactile icon) for three distance steps of 250 m, 150 m, and 50 m. The information is presented to the users by activating the four tactile actuators either under the left or right leg of the driver. The results of an evaluation in the simulator show that the tactile interface helps to reduce the visual burden of the drivers. We take the opportunity to explore the tactile encoding for spatial information in the real driving environment. van Erp and van Veen encoded a distance information in the form of rhythm patterns though it is possible to explore more methods of distance encoding. The proof-of-concept study shows that using vibro-tactile displays in the car is useful for presenting distance information.

In the previous research, torso based tactile displays are successfully employed to present navigation information to the blind users and pedestrians but parameters still require exploration in the automobiles. In the previous studies [9, 11, 14, 19], a number of vibro-tactile encoding schemes are compared to display distance information to the team players, pedestrian and blind users. Besides previous proof-of-concept studies [17] the tactile parameters are still required to explore to discover an appropriate approach of encoding distance with vibro-tactile signals in the car navigation system. In this paper a similar comparative approach is used to explore the tactile parameters to encode distance information in the car navigation system.

EXPLORING DISTANCE ENCODING WITH VIBRO-TACTILE SIGNALS

Car navigation systems provide route guidance to the driver towards a destination [15]. In our study, we used a tactile waist belt to provide turn by turn directions and distance information to the driver. Figure 1 presents example cues that are conveyed to the driver through the tactile belt while ap-

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2http://www.audiworld.com/news/05/naias/aaqc/content5.shtml
proaching the actual turn. In order to convey the direction *left*, the tactile belt indicates left by activating vibrators on the left side. The vibro-tactile signals provide information about the four categories of distance as proposed by Fukuda [3]: (1) Very-far, (2) Far, (3) Near, and (4) Turn-now. The driver make turning decisions by following the vibro-tactile instructions concerning the direction and distance while approaching the crossing. This section describes our vibro-tactile distance encoding in the car navigation system and the practical approach that we adopted to explore the design space.

**Vibro-tactile Distance Encoding**

There are many potential ways to use vibration for encoding distance. According to [1, 18] the tactile parameters that can be modified to encode information in general are frequency, amplitude, waveform, duration, rhythm and body location. The frequency is the number of cycles per second [8]. Vibration stimuli will be detected when the amplitude exceeds a threshold which is dependent on several parameters including frequency [18]. The parameters of frequency and amplitude are not well suited to encode information [20]. The change in voltages results in change in frequency and amplitude simultaneously. The change is almost linear given in Precision Microdrive³. So we can treat the frequency and amplitude as one parameter of intensity by following the approach in [11]. Furthermore, we cannot modify the waveform of the signal as its manipulation would require specific hardware [18]. Further parameters for encoding distances are rhythm and duration. The rhythm is created by grouping a number of pulses in a temporal pattern. Varying the duration of the vibro-tactile signal means to vary the length of a single pulse.

We can design different vibration patterns by modifying the intensity, rhythm, duration, and the body location. In this study the body location of vibro-tactile cues is already used for presenting direction as the vibro-tactile waist belt uses the left and right vibrators to encode the direction of the upcoming turn. Thus, it cannot be used further for distance encoding.

In summary, encoding distance by vibration can be conducted by altering the parameters intensity, rhythm, and duration. These parameters can be altered individually or in combination. Following options are available for the adjustment: intensity only, rhythm only, duration of the signal, intensity and rhythm, intensity and duration, and rhythm and duration. In order to validate, whether all of these options were easy to perceive, to distinguish and to interpret by the driver, we investigated them in a first pilot study.

**Pilot study**

The overall aim of the pilot study was to explore the usefulness of the different ways of encoding distance information with vibro-tactile signals. We conducted the pilot study to select the possible tactile parameters for encoding the distance information in the real driving scenarios. The results of the study helped us in the design of vibro-tactile distance encodings for a further comparative evaluation. In addition, the pilot study was conducted to provide the proof-of-concept of displaying distance information with only tactile feedback on the real road.

**Participants, apparatus and Procedure**

One female participated in the pilot study. She had 25 years of driving experience. The vibro-tactile signals are used to present distance information to the participant. The participant tested six options of vibro-tactile distance encoding in seven design solutions. We adopted the approach of thinking aloud to collect the participant’s comments and observations. We made videos for data collection. We measured the vibro-tactile signal perception and distance categories.

The distance signals were controlled by an experimenter on the backseat. The participant was trained on all the designs before going to the driving sessions. The participant drove in multiple sessions. The participant drove at least two times for each design. The participant was speaking whatever she thinks about the vibro-tactile signal perception and categories of distance. The videos were analyzed post-studies to collect the results.

**Results and discussions**

In summary, we found that the following designs are acceptable according to the participant’s comments: rhythm based distance encoding, intensity and rhythm based distance encoding, duration and rhythm based distance encoding. The respective category of distance relative to the quantitative range of distance is given in Table 1. In the following, we will discuss our observations and the driver’s comments of the pilot study in detail.

**Categories of distance:** In distance encoding, the signal of *turn-now* is required to be comparatively intense and easy to identify to make sure that the driver has to take turn at that moment. According to observations, the vibration signal for *turn-now* will be few meters (i.e. 10m) before the next crossing while driving on the street.

**Vibration patterns in automobiles:** The driver commented that "I get strong sensations with less number of pulses, and while increasing the number of pulses feeling-wise it is less intense". The driver gets smooth sensations with a higher number of pulses in a small time interval (e.g. minimum six pulses per second). The vibration pattern sensed intense and distinct if less pulses take place in a longer time interval (e.g. 2 pulses per second). The participant commented that "The vibration is not easy to feel and I am undecided between different levels of intensity" for only intensity-based distance encoding. We observed that the participant annoyed by the intensity only vibro-tactile signal. Furthermore, it was difficult for the participant to understand the distance information. We discovered that rhythm is an important parameter for vibro-tactile information encoding in the car navigation system. We discovered that it is possible to get appropriate rhythm by changing a number of pulses while keeping the constant level of the intensity. Consequently, it is difficult to

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Distance encoding in vibro-tactile cues

We discovered three promising vibro-tactile distance encodings based upon our pilot study and observations. The designs are composed of vibration duration, intensity, and rhythm. In the three designs we encode the categories of distances (see Table 1). The first design utilized the parameter rhythm, the second one utilized the parameters rhythm and intensity, and the third design made use of rhythm and duration. In the first two designs, the driver perceives a very smooth vibration at the distance of very-far and a very intense vibration at the distance of turn-now. The third design – rhythm and duration encoding – conveys countable pulses to the driver. The three designs are explained with the help of graphical representation (see Figures 2), where the vertical axis presents the level of intensity and the horizontal axis presents time in milliseconds (ms). Furthermore, the four categories of distance are presented from the top to the bottom in the diagrams. The technical characteristics of the three designs are outlined in the following:

### Rhythm based distance encoding:

The graphical visualization of only rhythm based distance encoding is shown in Figure 2. The encoding of a distance signal is presented with its intensity and length. The event is composed of pulses per second. A pulse is composed of its activation and deactivation states. The intensity is same for all the four events. If we observe from the top to the bottom the design consists of 25 pulses for the very-far. The far, near and turn-now consist of 10 pulses, 6 pulses, and 2 pulses respectively.

### Rhythm and intensity based distance encoding:

The graphical visualization of the intensity and rhythm based distance encoding is presented in Figure 2. The distance is encoded in pulses per second with variable intensity. A pulse is composed of its activation and sleeping states. If we look from top to bottom in the diagram an event of very-far is composed of 25 pulses with 70% of intensity level. On the second place the event of far is composed of 10 pulses with 70% of intensity. On the third place the event of near is composed of 6 pulses with 80% of intensity. And in the bottom the turn-now event consists of 2 pulses with maximum intensity.

### Rhythm and duration based distance encoding:

The graphical visualization of the duration and rhythm based distance encoding is presented in Figure 2. In this design the pulses are more intense and less in a number. The distance is presented with a number of pulses in the given time along with its intensity level. A pulse is shown with its activation and deactivation states. The first event is composed of 4 pulses of the length of 2.5 seconds. The inter-stimulus interval between the pulses is 313 ms. The second event consists of 3 pulses of the length of 2 seconds. The inter-stimulus interval between the pulses is 333 ms. The third event is encoded as 2 pulses of length of 1.5 seconds. The inter-stimulus interval between the pulses is 375 ms. The fourth event is encoded as one pulse in a second with 500 ms inter-stimulus interval.

On the basis of the pilot study, we proposed the three different methods of distance encoding based on: only rhythm, intensity and rhythm and duration and rhythm. In the following section, we present the design of the experiment in which we compared the methods of distance encoding.

### EVALUATION

The goal of the study is to compare the different approaches to encode distance information with vibro-tactile signals.

We aim to investigate the most simple vibro-tactile distance encoding for the driver that leads to successful task completion. The comparative evaluation investigates the specified questions:

<table>
<thead>
<tr>
<th>Category of Distance</th>
<th>Distance (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Far</td>
<td>200-150</td>
</tr>
<tr>
<td>Far</td>
<td>100-80</td>
</tr>
<tr>
<td>Near</td>
<td>50-30</td>
</tr>
<tr>
<td>Turn Now</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1. The quantitative categories of four distances.
Q1: Will the participants perceive turn by turn distance information without support of visual and auditory modalities in the car?

Q2: Which one of the encodings – rhythm, rhythm and intensity, rhythm and duration – is the most usable encoding?

Q3: Which distance encoding helps the driver to make the least number of information perception / interpretation errors?

Q4: What are common errors that participants make to interpret distance information by using the tactile display?

**Experiment design**
Our experiment consists of one independent variable. The vibro-tactile signal presents the direction and distance information to the participants. We compared the three vibro-tactile distance encodings while driving in real urban environments. The approach of the experiment was within subject, with 3 different routes and 3 different vibro-tactile encodings of distance. In the within subject approach the different experimental conditions are the three vibro-tactile distance encodings and the same participants have been used in all the conditions.

**Dependent measures**
Considering the questions for the evaluation Q1 to Q4, we selected the measures of usability of the designs, information perception errors and cognitive workload as dependent measures.

**Usability of the designs:** We measure usability in the terms of information perception, learnability, length of vibro-tactile signal, ease of use, and user’s judgment rating on the design. We asked the participants to rate the design’s usability on a questionnaire after completing each route.

**Information perception errors:** Information perception errors are the number of errors made by the participant in identifying the category of distance. We measure the number of participants’ wrong responses on the categories of distance for quantifying how many errors they made in perceiving the distance information. Furthermore, we analyzed how they interpreted the categories of distance.

**Distraction:** We analyzed the drivers’ responses and videos to measure the distraction.

**Participants**
We evaluated a total of 13 participants, 1 female and 12 male in our experiment. The participants were between 20-40 years old. All participants voluntarily participated in the experiment. Each participant completed all three sessions of the experiment. The participants have in the average 12 years of driving experience. We conducted (3*13) driving sessions with all participants in the whole study. We evaluated 3 participants after sunset and 10 in daylight. All participants completed assigned tasks easily in both conditions.

**Apparatus**
We used a fully automatic Volkswagen Touran car in all sessions. The tactile belt is used to provide navigational aid in all three driving sessions (see Figure 3). The tactile belt is integrated to be worn around the waist of the driver. The fixed circumference of 90 cm is made up of a fabric in the shape of a flexible tube. The tactors are sewed into the fabric tube. These tactors are vibrating components of Samsung SGH A400, size of 11 mm. The six tactors are distributed equally around the waist of the participant. We have used the questionnaires, video recording, and screen captures for the collection of data.
and incorrect responses of the driver e.g. the participant’s response on very-far as far can be considered as meaningful information. On sensation of the vibration signal the driver guesses the category of distance by thinking aloud. Later, an analyzer watched the screen capturing segment with video. The analyzer presses the keys according to the response of the participant about the information signal. The information produced in the procedure is saved in a text file. The videos are observed two times by the analyzer.

Procedure
The distance signals are controlled by the experimenter. The experimenter is seated next to the driver. During the driving session the four categories of distances are presented to the next crossing. We presented the categories of distance according to the length between two crossings e.g. all four categories of distance are displayed to the participant, if the length (in meters) is in the range of very-far distance (see Table 1). Furthermore, we displayed the 3 categories of distances if the length is in the range of the far distance and so on. We have created random sequences of the designs to balance any learning effect.

Before going to the venue, we explained the whole process of the experiment and trained each participant on all designs. Each participant was trained on the distance designs in five minutes sessions before leaving for real driving. The training was repeated before the beginning of every session.

The participants were relying on the tactile belt to drive from origin to the destination. Turn by turn direction is displayed by tactile feedback. Each participant drives according to a random sequence of designs in the experiment. The participant is again trained on the first design in the sequence until he will be able to confidently recognize the signals presenting the categories of distance. In addition, the graphical presentation of the different designs – as shown in Figures 2– have been provided. After completing the first route the driver is asked to park the car on a safe place and to fill out the questionnaires. Then the driver is trained on the second design in the sequence until he will be able to confidently recognize the signals presenting the categories of distance and so on.

Figure 4 presents the three different routes the participants had to drive. The destination of a route represents the start of the next route. The lengths of route 1, route 2, and route 3 are 1.3 km, 1.2 km and 1.4 km respectively. The order of the designs was changed amongst the participants. However, we kept the same order of the driving routes.

RESULTS
All the participants were able to complete all the driving sessions. In the following, the results are divided into quantitative and qualitative results. The quantitative results provide the dependent measures like usability of the vibro-tactile distance encodings, and information perception errors. We applied statistical test to analyze the quantitative results. Similarly, we collected additional observations and the participants’ comments regarding the vibro-tactile distance encodings in the qualitative measures.

In the following, we will discuss the quantitative results of our evaluation.

Quantitative results
In the following we present the quantitative results of our evaluation, structured with respect to the dependent measures (see Section ). We applied a non-parametric Friedman’s ANOVA test on data collected from the questionnaire to measure usability of the vibro-tactile distance encodings. Furthermore, to know the difference between individual conditions we applied Wilcoxon tests on each pair of conditions. We applied a simple descriptive statistics on the quantitative data collected from the videos and screen captures to measure information perception error. The results are presented with the help of boxplot and simple bar charts.

Usability of the distance encodings
The participants ranked the designs as most preferred, preferred, and least preferred. Figure 5 presents the participants’ ratings for the three vibro-tactile designs. The rhythm and duration based distance encoding is the most preferred design according to the statistics. The rhythm and intensity based distance encoding is rated as preferred. The rhythm based distance encoding is rated as the least preferred design by the participants.

Figure 6 presents the participants’ response on the learnability of the designs. The Friedman’s test shows that learnability of vibro-tactile distance designs are significant different (Chi-Square=9.19, \( p < .05 \)). Further, the Wilcoxon test depicts that the learnability score of duration and rhythm based distance encoding is significantly higher than intensity and rhythm based distance encoding, \( p < .025 \). Similarly, learnability score of duration and rhythm based distance encoding is significantly higher than rhythm based distance encoding, \( p < .025 \).

In Figure 7 the boxplot presents the participants’ responses about information perception. The Friedman’s test shows that the participants perceive information significantly different in all designs (Chi-Square=10.286, \( p < .05 \)). Further,
the Wilcoxon test shows that the information perception in duration and rhythm based distance encoding ranked significantly positive than intensity and rhythm based distance encoding, \( p < .025 \). There is no difference in information perception of duration and rhythm based distance encoding and rhythm based distance encoding, \( p = .044 \).

Figure 8 presents the participants’ responses on the length of vibro-tactile signal. The participants’ acceptance of the length of vibro-tactile signals in the three designs is significantly different (Chi-Square=6.884, \( p < .05 \)). The Wilcoxon test shows no significant difference exists in participants’ preferences on the length of the vibro-tactile signal between duration and rhythm based distance encoding and intensity and rhythm based distance encoding, \( p = .034 \). Similarly, no significant difference exists in participants’ preferences on the length of the vibro-tactile signal between duration and intensity based distance encoding and rhythm based distance encoding, \( p = .067 \).

The Friedman’s test does not reveal any significant difference in the rating of the design judgment in all three vibro-tactile distance encodings, (Chi-Square=4.478, \( p = .107 \)).

According to the Friedman’s test there is no significant difference in the ease of use of the three designs, (Chi-Square=2.600, \( p = .273 \)).

Information perception errors
The three designs have been compared by the number of errors made by the drivers in recognizing the category of distance. The percentages in Figure 9 show that the participants made the least number of mistakes in recognizing all categories of distance in the duration and rhythm based distance encoding. In the rhythm based distance encoding the drivers made most of the errors in perceiving a very-far distance, 35.7%. We observed the maximum error rate in recognizing far, near, and turn-now distances in the intensity and rhythm based distance encoding, 25.5%, 26%, and 7.2% respectively.

Figure 10 shows that regarding the rhythm based distance encoding the drivers made most of mistakes in recognizing very-far as far, 33.3%. Furthermore, the drivers made equal amount of mistakes in recognizing far as very-far and near, 7.7%. The participants made mistakes in recognizing near as far, 17.5%.

Figure 11 illustrates that most of the times the drivers made mistake in guessing the very-far distance as far, 12.8% in the rhythm and intensity based distance encoding. The drivers made higher number of errors in recognizing near as far, 26%.

A few mistakes of the participants were observed in rhythm
and duration based distance encoding according to Figure 12.

Observations and drivers’ comments
The comments and responses have been collected with the help of video recordings. In general most of the participants liked the vibro-tactile display in the car navigation system. The participants stated that the tactile vibration is sensed more effectively in sitting position inside the car. In the following we structured qualitative findings by the aspects of engagement with the environment, visual and auditory modalities, driver distraction and categories of distance.

Engagement with the environment
We observed from the videos that the vibro-tactile feedback did not cause any visual distraction. In each driving session the participants were freely commenting about the houses and shops on the way. The participants stand no obstruction in thinking aloud and using the tactile display simultaneously. The drivers discovered the vibro-tactile feedback to be quite helpful while talking to the other passengers and concurrently searching a specific location in the city. The participants do not need to slow down the speed of the car to recognize and understand the vibro-tactile feedback. In total the participants missed out 3 out of 221 turns in the whole experiment. A participant commented that “I have enjoyed this drive, because the system was not grabbing my attention at all”.

Visual and auditory modalities
In the responses to questions regarding the overall impression of the prototype 85% of the participants told that they like the vibro-tactile signals for displaying direction and distance. The idea of replacing the auditory feedback with the tactile feedback is preferred by 93% of participants. The participants commented that the tactile feedback is less irritating than the auditory feedback. The tactile interface is preferred for directional information by the participants. Two participants told that they would prefer to have a visual display with the tactile display. So, the visual displays can help in such situations when participants are not confident about the tactile signal.

Driver’s distraction
No visual distraction is evident from the video analysis and the experimenter observations. We observed that in the rhythm based distance encoding the maximum intensity used to present all categories of distance was irritating for the drivers of the car. In the rhythm and intensity based distance encoding a lower intensity to indicate very-far and far is liked by the participants. One participant told “I will prefer lower intensity to present longer distances because it’s not disturbing”. Another participant commented “It is good to present very-far and far with low intensity signal to get warning before the next turn”.

Categories of distance
The participants told that they can easily differentiate the vibro-tactile signals of very-far and far with turn-now. The participants preferred to get the signal of turn-now very close to the turn. We observed that the smooth signals for the distance very-far and far are less irritating for the participants. One participant did not felt the very-far signal in the rhythm...
The results show that the rhythm and intensity based distance encoding is quite distinct from previously proposed schemes [17, 19]. The results demonstrated that the countable pulses encoding is most successful among all tested designs. The driver made considerably less errors in perceiving distance information. Therefore, it is discovered as an appropriate approach to encode distances through vibro-tactile signals. In the following the results regarding our research questions for this study (Section 4) are discussed.

Q1: Will the participants perceive turn by turn distance information without support of visual and auditory modalities in the car? The participants missed the crossing only 3 times in the whole experiment which supports the argument that vibro-tactile signals can be used to present distance information for the whole route while driving. We concluded from the qualitative results that the participants asked for visual display in case they were not sure regarding the meaning of the vibro-tactile signal. The findings like engagement with environment and the participants’ preferences to the tactile display support the fact that tactile feedback with no visual and auditory attention is beneficial for providing navigation information in many situations. So we determined that the vibro-tactile signals can be qualified to present spatial information in the car navigation system.

Q2: Which one of the encodings – rhythm, rhythm and intensity, rhythm and duration – is the most usable encoding? The results show that the rhythm and duration based distance encoding is proved to be more usable among all tested designs. In addition, it is easier for the driver to learn the distance information in rhythm and duration based distance encoding as compared to the other encodings. The concept of countable pulses for encoding distance information is quite distinct from previously proposed schemes [17, 19]. The results demonstrated that the countable pulses encoding is usable in the car navigation system. Furthermore, the participants believe that afterwards they can also gain confidence on the vibro-tactile rhythm based distance encoding approach with more practice.

Q3: Which distance encoding helps the driver to make the least number of information perception / interpretation errors? The participants made the least number of errors on the rhythm and duration based distance encoding compared to the other two designs. Besides rhythm, the duration of the vibro-tactile signal plays an important role in the vibro-tactile distance encoding in the car. The simplicity of the vibro-tactile information encoding information allowed the drivers to easily recognize the meaning of the signal. The two designs, rhythm based distance encoding and rhythm and intensity based distance encoding, are composed of similar rhythm patterns with different levels of intensity. In both designs the results differ insignificantly in terms of mistakes of participants in perceiving distances. So, we conclude that modification in the level of intensity does not impact significantly on perception of distance in the designs. We also observed from our qualitative results that the lower intensity is less irritating for longer distance. In summary the approach of rhythm and intensity based distance encoding can be beneficial in some aspects (e.g. for longer distances lower frequency is not disturbing) but the approach of intensity based distance encoding is not mainly contributing. The results support the concept of quiet communication in the car proposed by [17]. The results encourage the use of tactile display for complex information in the car navigation systems besides the fact that the drivers need backup support of visual and auditory modalities [7].

Q4: What are common errors that participants make to interpret distance information by using the tactile display? The drivers tended to make the least number of errors while they get opportunity of counting the number of pulses. From qualitative results we can conclude that the tactile display does not imply any visual distraction, thus, the drivers are able to fully concentrate on the primary driving task. Our findings support the fact that the tactile displays in the car navigation systems cause less amount of distraction to the driver [17].

The results of the experiment can only be applied to the street scenarios. The distances are decided for categories of very-far, far, near, and turn-now while driving in a residential area. The vibro-tactile signals were controlled by the experimenter, so we cannot neglect the chance of human error in the experiment. The gender aspect is also limitation of the study because mostly male participants have taken part. The results cannot be generalized for old drivers.

CONCLUSION
From previous studies [6, 17] we may assume that tactile feedback can be used as an alternative way to present distance information to the driver without support of the visual or auditory displays. We investigated in this paper three vibro-tactile distance encodings based on rhythm, intensity and duration. To investigate the designs we conducted an evaluation on a real navigation scenario in an urban environment.
The study shows that the tactile feedback is quite helpful for the navigation in the environment without support of visual or auditory displays. The tactile design which modifies the parameters rhythm and duration of the signal is proved to be most successful among the three tested designs. By this design the driver receives a tactile stimulation through countable vibration pulses, which encode the distance information. We can conclude that the approach can be applied to encode distance information in the most complex road scenarios. However, the present study is carried out in the urban environments and it is not clear, whether the results can be generalized for other environments, such as motorways or highways and how the distance categories have to be adapted to other scenarios. This issue remains for following analysis.

In the near future, further investigations will be conducted, in particular, to find out if there are any gender or age differences regarding the acceptance and usability of tactile presentations while driving. For our long term research, we have identified several research questions regarding tactile presentations for people on the move, such as:

1. What other information besides turn by turn instructions can be presented with tactile feedback to the user, in order to improve safety and comfort?
2. Is it possible to transfer the findings also to cyclists, motorcyclists, and pedestrians?

Information presentation in cars is currently a topic of high interest in the public and transportation industry. On the one hand, there is a huge demand from the end users’ point of view to ease the ability to move from one location to another with more safety and comfort. On the other hand, new technical developments allow advanced and innovative interaction techniques in cars, which will be an important argument for buying cars in the future. Tactile displays will have a great impact on future developments in human machine interface design of automobiles.

REFERENCES