Manipulating Vibro-Tactile Sequences on Mobile PC

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Abstract. Tactile memory is the crucial factor in coding and transfer of the semantic information through a single vibrator. While some simulators can produce strong vibro-tactile sensations, discrimination of several tactile patterns can remain quite poor. Currently used actuators, such as shaking motor, have also technological and methodological restrictions. We designed a vibro-tactile pen and software to create tactons and semantic sequences of vibro-tactile patterns on mobile devices (iPAQ pocket PC). We proposed special games and techniques to simplify learning and manipulating vibro-tactile patterns. The technique for manipulating vibro-tactile sequences is based on gesture recognition and spatial-temporal mapping for imaging vibro-tactile signals. After training, the tactons could be used as awareness cues or the system of non-verbal communication signals.

1 Introduction

Many researchers suppose that the dynamic range for the tactile analyzer is narrow in comparison to visual and auditory ones. This fact is explained by the complex interactions between vibro-tactile stimuli, which are in spatial-temporary affinity. This has resulted in a fairly conservative approach to the design of the tactile display techniques. However, some physiological studies [1] have shown that a number of possible “descriptions” (states) of an afferent flow during stimulation of the tactile receptors tend to have a greater amount of the definite levels than it was previously observed, that is more than 125. The restrictions of the human touch mostly depend on imaging techniques used, that is, spatial-temporal mapping and parameters of the input signals. As opposed to static spatial coding such as Braille or tactile diagrams, tactile memory is the crucial factor affecting perception of the dynamical signals similar to Vibratese language [7], [9].

Many different kinds of devices with embedded vibro-tactile actuators have appeared during the last two years. There is a stable interest to use vibration in games including small-size wearable devices like personal digital assistants and phones [2], [3], [14]. The combination of small size and low weight, low power consumption and noise, and human ability to feel vibration when the hearing and vision occupied by other tasks or have some lacks, makes vibration actuators ideal for mobile applications [4], [10].

On the other hand, the absence of the tactile markers makes almost impossible for visually impaired users interaction with touchscreen. Visual imaging is dominant for touchscreen and requires a definite size of virtual buttons or widgets to directly manipulate them by the finger. Among recent projects, it is necessary to mention the works of Nashel and Razzaque [11], Fukumoto and Sugimura [6] and Poupyrev et al [12]. The authors propose using different kinds of the small actuators such as piezoceramic bending motor [6], [12] or shaking motor [11] attached to a touch panel or mounted on PDA.

If the actuator is placed just under the touch panel, the vibration should be sensed directly at the fingertip. However, fingertip interaction has a limited contact duration, as the finger occupies an essential space for imaging. In a case of blind finger manipulations, a gesture technique becomes more efficient than absolute pointing when making use of the specific layout of software buttons. A small touch space and irregular spreading of vibration across touchscreen require another solution. If the actuator is placed on the backside of the mobile device, vibration could be sensed at the palm holding the unit. In this case, the mass of the PDA is crucial and impacts onto spectrum of playback signals [4], [6].

From time to time vibro-tactile feedback has been added to a pen input device [13]. We have also implemented several prototypes of the pen having embedded shaking motor and the solenoid-type actuator. However, shaking motor has a better ratio of the torque to power consumption in a range of 3 – 500 Hz than a solenoid-type actuator. The vibro-tactile pen certainly has the following benefits:

- the contact with the fingers is permanent and has more touch surface, as a rule, two fingertips tightly coupled to the pen;
- the pen has smaller weight and vibration is easily spread along this unit, it provides the user with a reliable feeling of different frequencies;
- the construction of the pen is flexible and admits installation of several actuators which have a local power source;
- the connection to mobile unit can be provided through a serial port or Bluetooth, that is, the main unit does not require any modification.

Finally, finger grasping provides a better precision compared with hand grasping [5]. Based on vibro-tactile pen we developed a special technique for imaging and intuitive interacting through vibration patterns. Simple games allow to facilitate learning or usability testing of the system of the tactons that might be used like awareness cues or non-verbal communication signals.

2 Vibro-Tactile Pen

The prototype of vibro-tactile pen consists of a miniature DC motor with a stopped rotor (shaking motor), electronic switch (NDS9959 MOSFET) and battery having the voltage of 3 V. It is possible to use internal battery of iPAQ, as an effective current can be restricted to 300 mA at 6 V. Both the general view and some internal design features of the pen are shown in Fig. 1.

There are only two control commands to start and stop the motor rotation. Therefore, to shape an appropriate vibration pattern, we need to combine the pulses of the current and the pauses with definite duration. Duration of the pulses can slightly change the power of the mechanical moment (a torque). The frequency will mostly be determined by duration of the pauses.

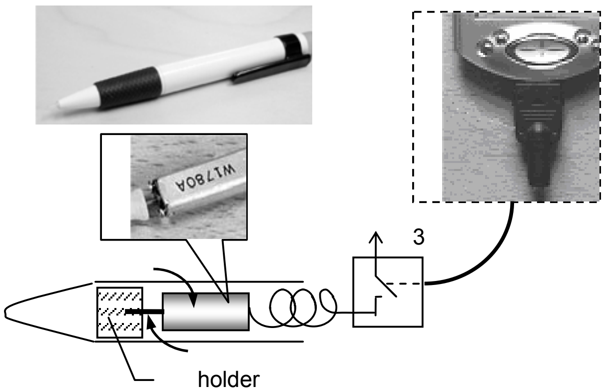

Fig. 1. Vibro-tactile pen: general view and schematics.

We used the cradle connector of Compaq iPAQ pocket PC which supports RS-232 and USB input/output signals. In particularly, DTR or/and RTS signals can be used to realize the motor control.

The software to create vibro-tactile patterns was written in Microsoft eMbedded Visual Basic 3.0. This program allows shaping some number of vibro-tactile patterns. Each of the tactons is composed of two sequential serial bursts with different frequency of the pulses. Such a technique based on contrast presentation of two well-differentiated stimuli of the same modality facilitates shaping the perceptual imprint of the vibro-tactile pattern. The number of bursts could be increased, but duration of the tacton shall be reasonable and shall not exceed 2 s. Durations of the pulses and pauses are setting in milliseconds. Number of pulses determines the duration of each burst. Thus, if the pattern consists of 10 pulses having frequency of 47.6 Hz (1+20 ms) and 10 pulses having frequency of 11.8 Hz, (5+80 ms) vibro-tactile pattern has the length of 1060 ms. All patterns are stored in the resource file "TPattern.txt" that can be loaded by the game or another application having special procedures to decode the description into output signals of the serial port according the script.

3. Method for Learning Vibro-Tactile Signals

Fingertip sensitivity is extremely important for some categories of physically challenged people such as the profoundly deaf, hard-of-hearing people and people who have low vision. We can find diverse advises how to increase skin sensitivity. For instance, Stephen Hampton in "Secrets of Lock Picking" [8] described a special procedure and the exercises to develop a delicate touch.

Sometimes, only sensitivity is not enough to remember and recognize vibration patterns and their combinations, especially when the number of the tactons is more than five. While high skin sensitivity can produce strong sensation, the discrimination of several tactile stimuli can remain quite poor. The duration of remembering tactile pattern depends on many factors which would include personal experience, making of the individual perceptive strategy, and the imaging system of alternative signals [7].

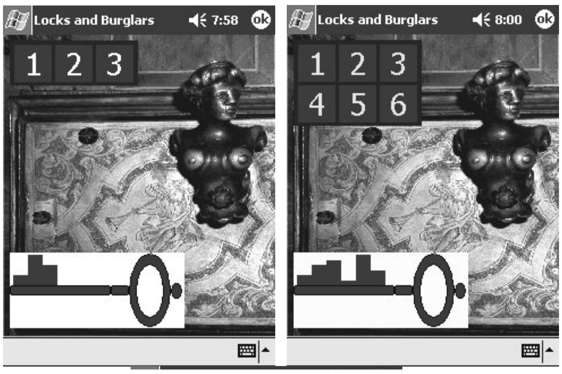

Fig. 2. Three levels of the game "Locks and Burglars".

We propose special games and techniques to facilitate learning and manipulation by vibration patterns. The static scripts have own dynamics and provoke the player to make an individual strategy and mobilize perceptive skills. Let us consider a version of the game for the users having a normal vision.

The goal of the "Burglar" is to investigate and memorize the lock prototype to open it as fast as possible. There are three levels of difficulty and two phases of the game on each level. In the "training" mode (the first phase), the player can touch the lock as many times as s/he needs. After remembering tactons and their position, the player starts the game. By clicking on the label “Start”, which is visible in training phase, the game starts and the key will appear (Fig. 2). The player has the key in hand and can touch it as many times as s/he needs. That is a chance to check the memory.

After player found known tactons and could suppose in which position of the lock button s/he had detected these vibrations before, it is possible to click once the lock button. If the vibration pattern of the button coincides with corresponding tacton of the key piece, the lock will have a yellow shine. In a wrong case, a shine will be red. Repeated pressing of the corresponding position is also being considered as an error.

There is a restricted number of errors on the each level of the game: single, four and six allowed errors. We assumed that 15 s per tacton is enough to pass the third level therefore the game time was restricted to 2.5 minutes. That conditions a selection of the strategy and improves learnability. After the player did not admit the errors at all the levels, the group of tactons could be replaced. Different groups comprising nine tactons allow learning whole vibro-tactile alphabet (27 tokens) sequentially.

All the data, times and number of repetitions per tacton, in training phase and during the game are automatically collected and stored in a log file. Thus, we can estimate which of the patterns are more difficult to remember and if these tactons are equally hard for all the players, their structure could be changed.

Graphic features for imaging, such as numbering or positioning (central, corners) lock buttons, different heights of the key pieces, and “binary construction” of the tactons, each tacton being composed of the two serial bursts of the pulses, should facilitate remembering spatial-temporal relations of the complex signals in the proposed system.

Another approach was developed to support blind interaction with tactile patterns, as the attentional competition between modalities often disturbs or suppresses weak differences of the tactile stimuli. The technique for blind interaction has several features. Screenshot of the game for non-visual interaction is shown in Fig. 3. There are four absolute positions for the buttons “Repeat”, “Start” and two buttons are controlling the number of the tactons and the amount of the tactons within a playback sequence. Speech remarks support each change of the button state.

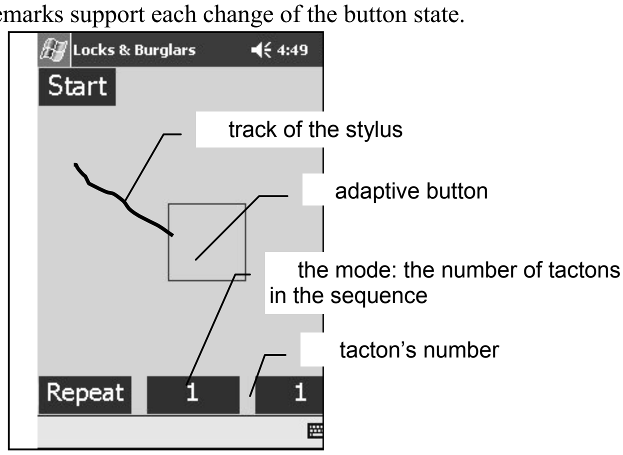

Fig. 3. The version of the game for blind player.

When blindfolded player should investigate and memorize the lock, s/he can make gestures along eight directions each time when it is necessary to activate the lock button or mark once the tacton by gesture and press down the button “Repeat” as many times as needed. The middle button switches the mode of repetition. Three or all the tactons can be played starting from the first, the fourth or the seventh position pointed by the last gesture.

Spatial-temporal mapping for vibro-tactile imaging is shown in Fig. 4. Playback duration for the groups consisting of 3, 6 or 9 tactons can reach 3.5 s, 7.2 s or 11 s including earcon to mark the end of the sequence. This parameter is important and could be improved when stronger tactile feedback could be provided with actuator attached to the stylus directly under the finger. In practice, only the sequence consisting of three tactons facilitates recognizing and remembering a sequence of the tactile patterns.

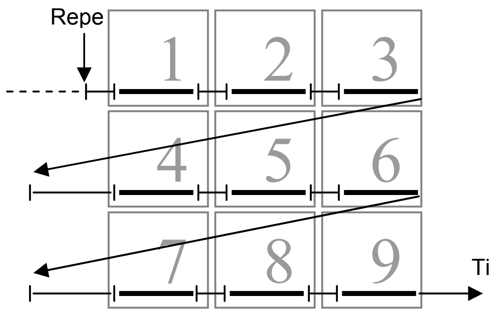

Fig. 4. Spatial-temporal mapping for vibro-tactile imaging: T_1 = 60 ms, T_2 = 1100 ms, T_3 = 300 ms.

To recognize gestures we used the metaphor of the adaptive button. When the player touches the screen, the square shape (Fig. 3) automatically changes position and finger or stylus occurs in the center of the shape. After the motion was realized (sliding and lifting the stylus), the corresponding direction or the button position of the lock will be counted and the tacton will be activated.

The button that appears on the second game phase in the bottom right position activates the tactons of the virtual key. At this phase, the middle button switches number of tactons of the key in a playback sequence. However, to select the button of the lock by gesture the player should point before what key piece s/he wishes to use. That is, the mode for playback of a single tacton should be activated. The absolute positions of software buttons do not require additional markers.

4. Evaluation of the Method and Pilot Results

The preliminary evaluation with able-bodied staff and students took place in the Department of Computer Sciences University of Tampere. The data were captured using the version of the game "Locks and Burglars" for deaf players. The data were collected concerning 190 trials in a total, of 18 players (Table 1). Despite of the fact, that the tactons have had low vibration frequencies of 47.6 Hz and 11.8 Hz, we cannot exclude an acoustic effect, as the players had a normal hearing. Therefore, we can just summarize general considerations regarding the difficulties in which game resulted and overall average results.

Table 1. The preliminary average results.

Level (tactons)	Trials	Selection time per tacton	Total selection time	Repeats per tacton	Err, %
1 (3)	48	3.8 s	12.4 s	4-7	7.7
2 (6)	123	3.4 s	16.8 s	3-13	13.3
3 (9)	19	1.7-11 s	47.3 s	4-35	55.6

The first level of the game is simple as memorizing of 2 out of 3 patterns is enough to complete the task. The selection time (decision-making and pointing the lock button after receiving tactile feedback in corresponding piece of the key) in this level did not exceed 3.8 s per tacton or 12.4 s to find matching of 3 tactons. The number of the repetitions to memorize 3 patterns was low, about 4 - 7 repetitions per tacton. The error rate (Err) was 7.7%. The error rate was counted as follows:

$$Err = \frac{[wrong\_selections]}{[trials] \times [tactons]} \times 100\% \quad . \qquad (\mathbf{2})$$

The second level of the game (memorizing six tactons) was also not very difficult. An average time of the selection per tacton was about 3.4 s and 16.8 s in a total to find matching of six tactons. The number of the repetitions to memorize six patterns was varied from 3 to 13 repetitions per tacton. However, the error rate increased up to 13.3%, it is also possible due to the allowed number of errors (4).

The third level (nine tactons for memorizing) was too difficult and only three of 19 trials had finished by the win. The average time of the selection has been changed from 1.7 s up to 11 s per tacton and reached 47.3 s to find matching of nine tactons. While a selection time was about 30% of the entire time of the game, decision-making occupied much more time and players lost a case mostly due to limited time. The number of repetitions to memorize nine patterns in training phase varied significantly, from 4 up to 35 repetitions per tacton. Thus, we can conclude that nine tactons require of a special strategy to facilitate memorizing. However, the playback mode of the groups of vibro-tactile patterns was not used in the tested version. The error rate was too high (55.6%) due to the allowed number of errors (6) and, probably, because of the small tactile experience of the players.

The blind version of the game was briefly evaluated and showed a good potential to play and manipulate by vibro-tactile patterns even in the case when audio feedback was absent. That is, the proposed approach and the tools implemented provide the basis for learning and reading of the complex semantic sequences composed of six and more vibro-tactile patterns.

5. Conclusion

We designed a vibro-tactile pen and software intended to create tactons and semantic sequences consisting of the vibro-tactile patterns on mobile devices (iPAQ pocket PC). Tactile memory is the major restriction for designing a vibro-tactile alphabet for the hearing impaired people. We proposed special games and techniques to facilitate learning of the vibro-tactile patterns and manipulating by them. Spatial-temporal mapping for imaging vibro-tactile signals has a potential for future development and detailed investigation of the human perception of the long semantic sequences composed of tactons. After training, the tactons can be used as a system of non-verbal communication signals.

Acknowledgments

This work was financially supported by the Academy of Finland (grant 200761), and by the Nordic Development Centre for Rehabilitation Technology (NUH).

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Discussion

[Fabio Paterno] I think that in the example you showed for blind users a solution based on screen readers would be easier than the one you presented based on vibro-tactile techniques.

[Grigori Evreinov] A screen reader solution would not be useful for deaf and blind-deaf users.

[Eric Schol] Did you investigate the use of force-feedback joystick ?

[Grigori Evreinov] Yes, among many other devices ; like force-feedback mouse, etc. But main goal of the research was the application (game), not the device