Audiotactile Feedback Design for Touch Screens

M. Ercan Altinsoy and Sebastian Merchel

Chair of Communication Acoustics, TU Dresden, Helmholtzstr. 10,
01069 Dresden, Germany
ercan.altinsoy@tu-dresden.de

Abstract. The use of touch sensitive displays and touch surfaces is just emerging and they are more and more replacing physical buttons. If a physical button is pressed, audio and tactile feedback confirms the successful operation. The loss of audiotactile feedback in touch sensitive interfaces might create higher input error rates and user dissatisfaction. Therefore the design and evaluation of suitable signals is necessary. In literature different researchers discuss implementation and evaluation of audio and tactile feedback for mobile applications using small vibration actuators, e.g. [1,…, 12]. However in ticket machines or automated teller machines the size of the actuator is not a limiting factor. Thus arbitrary vibratory stimuli can be generated. In this study, the tactile feedback is generated using an electro-dynamic exciter which allows amplitudes comparable to physical buttons. Real buttons normally produce multimodal feedback. Therefore multimodal interaction is an important issue for the touch screens. In this study, psychophysical experiments were conducted to investigate the design and interaction issues of auditory and tactile stimuli for touch sensitive displays and the combined influence of auditory and tactile information (i.e. vibration) on the system quality.

Keywords: Touch screens, multimodal interaction, auditory, haptic, evaluation, error rate.

1 Introduction

Haptic feedback brings the sense of touch (tactile sense) and force-feedback to multimedia applications in addition to the mostly utilised modalities i.e., the auditory and visual one. In many new applications like virtual reality, flight simulators and medical surgery, haptic modeling and simulation of different physical objects plays a pronounced role. Besides of the reality-based physical simulation, development of effects for perception-based intuitive haptic feedbacks is a big challenge.

The use of touchscreens, touch panels, and touch surfaces is growing rapidly because of their software flexibility and space and cost savings. They are more and more replacing physical buttons in different technical devices like mobile phones, hi-fi and TV-sets, navigation systems, ticket machines, cash-dispensers, etc. The big disadvantages of such kind of systems is the missing haptic feedback which is required for the confirmation of the successful operation. Several studies have concentrated on the technical solutions and new hardware issues for the haptic feedback implementation

M.E. Altinsoy, U. Jekosch, and S. Brewster (Eds.): HAID 2009, LNCS 5763, pp. 136–144, 2009.

in mobile applications using small vibration actuators [1, …, 12]. Pager motors, piezo-electric actuators, multi function transducers and electrotactile stimulators are possible actuators for such kind of systems. Hovewer the big disadvantages of these systems is that the actuators can not reproduce high amplitudes which is common for classical push-buttons, because of the restricted actuator size and the operating space. The studies of Hogan, Brewster and Johnson or Chang and O'Sullivan indicate that touch feedback in touchscreens increases not only productivity and make products easier to use, but also make user experiences more satisfying. In the study of Hogan, Brewster and Johnson, four different kinds of tactile stimuli (clicks) were evaluated regarding to their suitability to the different visual information and their perceived quality [3]. They have shown that by choosing congruent sets of audio/tactile feedback to be added to touchscreen visual buttons, not only are users' preconceptions of how the button should feel and sound met but also the perceived quality of the buttons is improved.

Several studies investigated the usability and the quality issues of ticket vending machines or automated teller machines [13, 14]. Most of the standard machines uses touch screen technology. One of the important error sources and quality problems for these machines is the missing tactile feedback similar to mobile phones. In ticket machines or automated teller machines the size of the actuator is not a limiting factor. Therefore it is possible to use big size actuators and reproduce high amplitude tactile feedbacks. In this study, the tactile feedback is generated using an electro-dynamic exciter which allows reproducing movement amplitudes comparable to physical push-buttons. Other advantages of the electro-dynamic exciter are the large frequency range and linear behavior.

The aim of this study is the evaluation of different haptic and auditory feedback signal forms and characteristics regarding their suitability to the touch screen applications. If auditory and tactile modalities are combined, the resulting multimodal percept may be a weaker, stronger, or an altogether different percept, and of course it is also possible that one modality can be dominant over the overall assessment related to the physical/perceptual ability, the nature of the task, or personal preference [15]. Besides of unimodal evaluations, further aim of this study is to gain a better understanding of the interaction of auditory and tactile information. In order to achieve these aims, experiments with unimodal and multimodal stimulus presentations were conducted and, especially, the effects of the perceptual discrepancy between the auditory and the tactile sensory modalities on the multi-sensory judgments were investigated.

2 Experiments

The first experiment is conducted to investigate the usability of tactile feedback. Different signal forms and characteristics are evaluated. The aim of the second experiment is to investigate the usability of the auditory feedback for touch screen applications. The third experiment is conducted to investigate audiotactile interaction effects.

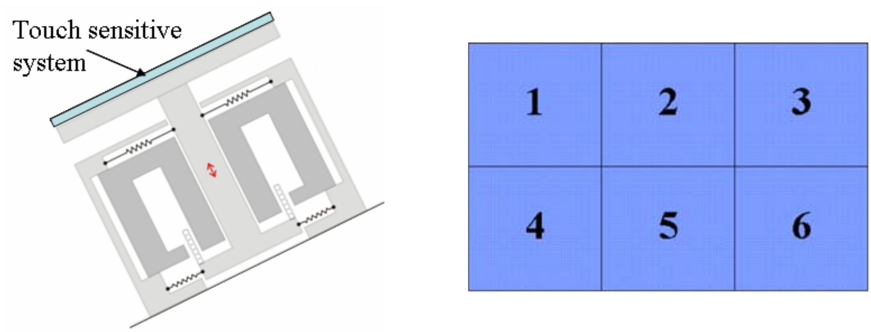
2.1 Tactile Feedback Design for Touch Screens

2.1.1 Subjects

Six subjects, three male and three female, aged between 20 and 28 years, participated in this experiment. The subjects were undergraduate students and voluntarily participated in this study. All subjects were right handed and they used their right hand for the experiment. All subjects had self-reported normal hearing.

2.1.2 Experimental Set-Up

In this paper a touch sensitive system is presented that reproduces event triggered audiotactile feedback. The tactile component is generated using an electro-dynamic exciter, which is mounted behind a touch screen. The surface of the panel is divided into 6 virtual buttons. The experimental setup and the layout are shown in Figure 1.



a) b)

Fig. 1. a) The experimental setup: Touch sensitive system with electro-dynamic exciter b) Interface printed on the touch screen, it is divided into 6 virtual buttons (2 rows, 3 virtual buttons for each row)

2.1.3 Stimuli and Procedure

The goal of this experiment is to evaluate different tactile feedback forms regarding their suitability for touch screens, while pressing a virtual button on a panel. Five different stimuli, which can be seen in Figure 2 are selected (duration = 0.05 s each): sin, triangle, square, $\sin^2$ and 50 Hz sinusoidal signal. The stimuli amplitude corresponds to the perpendicular displacement of the surface. Positive amplitude means movement towards the subject. The signal forms; sin, triangle, square and $\sin^2$ show big similarity with the physical push-button feedback. Therefore 50 Hz sinusoidal signal, which doesn't show similarity with the physical push-button feedback, is additionally tested. The maximum amplitude of the stimuli is 4 mm. The tactile stimulus sin 50 Hz has an amplitude of 0.5 mm.

For the evaluation experiment, a dialing-numbers task is used. The participants are asked to dial 16 numbers displayed on an extra screen as fast and accurately as they can. The execution time and the errors during the task were measured. For each participant, the task is repeated 6 times. During each task the tactile feedback

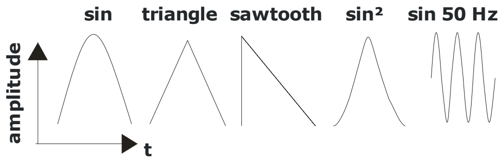


Fig. 2. Five different stimuli evaluated in this study. Length each = 0.05 s.

(5 stimuli used in the first experiment and 1 without any feedback) is the same for all 6 virtual buttons, but varies between different tasks.

After each task the participants were asked to evaluate the overall quality of the feedback, the suitability for confirmation and the comfort on a quasi continuous scale from "-5 (bad)" to "5 (good)". It was also possible to write down comments. The order of the stimuli was balanced between different participants.

2.1.4 Results

The performance of the subjects in terms of completion time and error rate of the dialing-numbers task is shown in Table 1. The difference between different feedback stimuli and none-feedback is significant for the number of errors and not significant in completion time. The number of errors of none-feedback is significantly larger than that of the other 5 kinds of feedback (Figure 3). The number of errors of sin feedback is significantly larger than that of sawtooth feedback.

Table 1. Performance for different tactile feedbacks showing mean values and standard deviations

	sin	triangle	sawtooth	sin ^2	sin 50 Hz	none	*F*	*p*	η
time to complete the dialing task in s	42.2±4.9	46.0±3.8	47.0±15.48	50.5±14.1	41.4±5.4	44.5±9.5	0.598	0.702	0.107
number of errors	1.0±1.1	1.3±1.5	0.2±0.4	1.3±1.7	0.9±0.7	4.5±2.5	8.030	0.000	0.616

To analyze the data of the evaluation part of the experiment (dialing-numbers task) ANOVA repeated measures were used. The results for the subjective valuation are shown in Table 2. Difference between different feedback stimuli and none-feedback is significant for overall quality and suitability for confirmation and almost significant for comfort of feedback.

Pairwise comparisons shows that the overall quality of none-feedback is significantly worse than that of the other five kinds of feedback, while they have no significant difference between themselves.

2.2 Auditory Feedback Design for Touch Screens

In this part of the study the touch sensitive system is used to reproduce event triggered audio feedback. Subjects and procedure were the same as in the first experiment.

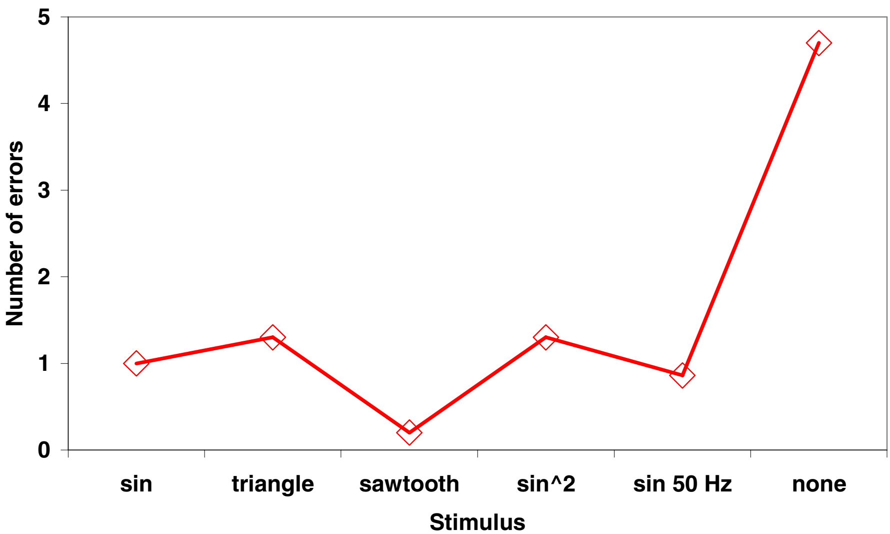


Fig. 3. Number of errors

Table 2. Perceptual quality ratings for different tactile feedbacks showing mean values and standard deviations

	sin	triangle	sawtooth	sin ^2	sin 50Hz	none	*F*	*p*	η
overall quality	2.5±1.52	2.2±1.47	2.7±2.25	2.3±1.6	2.5±0.9	-3.3±1.4	14.078	0.000	0.738
suitability for confirmation	2.5±1.64	2.5±1.64	2.8±1.60	2.2±1.8	2.5±1.4	-4.7±0.5	31.316	0.000	0.862
comfort of feedback	3.2±1.72	2.5±1.05	3.8±0.98	2.2±1.3	3.0±0.9	-1.3±3.6	4.382	0.051	0.467

Stimuli

The goal of this experiment is to evaluate different auditory feedback forms regarding their suitability for touch screens. Six different stimuli, which can be seen in Figure 4 are selected (duration = 0.05 s each).

Signal a, c and e are classical button sounds which have different frequency spectra and decay times. Particularly signal d has strong components at lower frequencies. Signal c has a broad band frequency spectrum with very short decay time. Signal a has some high frequency components. Signal b has a complex time sequence which is not common for classical push-button sounds. Signal d and f are DTMF (Dual-tone multi frequency) tones six and four which doesn't show any similarity with classical push-button sounds. The sound pressure level for all stimuli was 56 dB(A).

Results

The performance of the subjects in terms of completion time and error rate of the dialing-numbers task is shown in Table 3. The difference between different feedback stimuli is not significant for the number of errors and not significant in completion

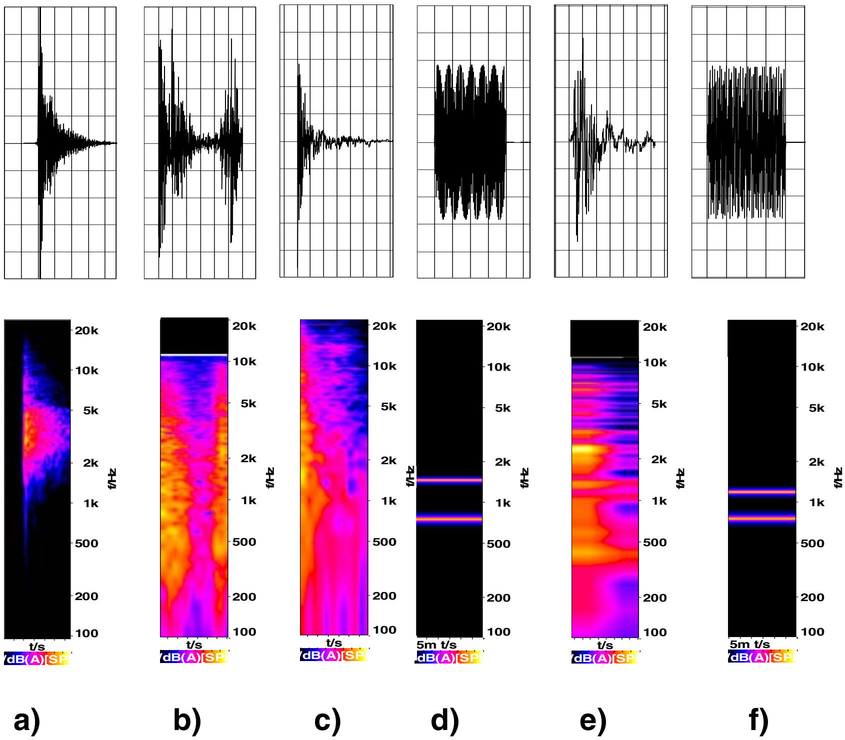


Fig. 4. Time sequences (above) and spectrograms (bottom) of six auditory stimuli. The color indicates the sound pressure level (yellow color: high sound pressure level, black color: low sound pressure level).

Table 3. Performance for different auditory stimuli (a,b,c,d,e and f) showing mean values and standard deviations

	a	b	c	d	e	f	*F*	*p*	η
time to complete the dialing task in s	45.0±3.4	44.6±3.9	47.4±2.6	47.4±3.9	48.9±3.9	44.2±4.3	6.598	0.651	0.607
number of errors	2.3±1.1	1.3±1.3	3.7±1.8	3.2±2.2	2.8±1.3	1.2±1.1	4.126	0.053	0.116

time. The number of errors for signals b and f are smaller than signals c,d,e and a. The reason can be that signals b and f are not typical button sounds. Particularly signal b has a characteristic time sequence.

To analyze the data of the evaluation part of the experiment (dialing-numbers task) ANOVA repeated measures were used. The results for the subjective valuation are shown in Table 4. The overall quality judgments seem very similar for different signal forms. Only signal c has a lower value than the others.

If tactile feedback only and auditory feedback only conditions are compared, it can be seen that The number of errors for auditory feedback alone conditions are larger

Table 4. Perceptual quality ratings for different auditory feedbacks showing mean values and standard deviations

	a	b	c	d	e	f	*F*	*p*	η
overall quality	2.9±0.7	2.8±1.1	1.5±2.6	2.6±1.3	2.8±0.9	3±1.3	16.103	0.000	0.766
suitability for confirmation	0.7±2.0	1.3±2.2	0.1±2.9	0.8±2.9	0.7±2.6	0.8±2.6	15.002	0.000	0.754
comfort of feedback	2.1±1.2	1.9±1.2	0.5±2.1	1.3±1.4	1.4±2.6	2.1±1.5	3.025	0.047	0.333

than for tactile feedback alone conditions. But the difference in the completion time between auditory and tactile signals is very small. The results show that there is not a big difference between overall quality judgments for auditory and tactile signals. However the suitability ratings for confirmation differ significantly between auditory and tactile signals. The tactile signals were evaluated more suitable for confirmation feedback.

2.3 Audiotactile Interaction

In this part of the study the touch sensitive system is used to reproduce event triggered audiotactile feedback. Subjects and procedure were the same as in the first and second experiment.

2.3.1 Stimuli

In this part of the study, two different tactile stimuli; $\sin^2$ and sin 50 Hz, are presented with different audio signals; signal a, b, c, d, e and f. The combined auditory with the tactile stimulus $\sin^2$ is called audiotactile 1 and the combined auditory with the tactile stimulus sin 50 Hz is called audiotactile 2.

2.3.2 Results

There is not a significant or important interaction effect regarding completion time and number of errors. The suitability for confirmation, the comfort ratings and the overall quality for audiotactile feedbacks are given in Table 5, 6, 7 and in Figure 5. The results of the audio only condition from the previous experiment are also given in the same tables for comparison.

The results show that if auditory signal is combined with the tactile signals, the tactile signal can alter the audio only ratings and almost all ratings increases. Particularly this effect is clearly observable for the ratings of the confirmation suitability

Table 5. *Confirmation suitability ratings* for different auditory and audiotactile feedbacks showing mean values and standard deviations (Reference: The rating of the tactile stimulus $\sin^2$ alone was 2.17±1.83 and the rating of the tactile stimulus sin 50 Hz alone was 2.5±1.5)

	a	b	c	d	e	f
only sound	0.7±1.9	1.3±2.2	0.1±2.9	0.8±2.9	0.7±2.6	0.8±2.6
audiotact. 1 (Tactile signal is **$\sin^2$**)	2.9±0.7	3.2±1.2	2.2±1.9	2.7±1.2	3.2±1.9	1.7±1.3
audiotact. 2 (tactile signal is **sin 50 Hz**)	3.5±0.8	2.4±1.8	2.1±1.0	3.4±1.3	2.0±1.6	2.9±1.7

Table 6. *Comfort ratings* for different auditory and audiotactile feedbacks showing mean values and standard deviations. (Reference: The rating of the tactile stimulus $\sin^2$ alone was 2.2±1.3 and the rating of the tactile stimulus sin 50 Hz alone was 3.0±0.9).

	a	b	c	d	e	f
only sound	2.0±1.2	1.9±1.2	0.5±2.1	1.3±1.4	1.4±2.6	2.1±1.5
audiotact. 1 (Tactile signal is **$\sin^2$**)	3.4±0.6	2.9±1.0	1.9±2.1	2.7±1.1	1.9±1.8	3.4±1.1
audiotact. 2 (tactile signal is **sin 50 Hz**)	2.8±0.6	2.6±0.7	1.9±2.6	2.8±0.7	1.7±1.3	2.5±1.5

Table 7. *Overall quality ratings* for different auditory and audiotactile feedbacks showing mean values and standard deviations. (Reference: The rating of the tactile stimulus $\sin^2$ alone was 2.3±1.6 and the rating of the tactile stimulus sin 50 Hz alone was 2.5±0.9).

	a	b	c	d	e	f
only sound	2.9±0.7	2.8±1.1	1.5±2.6	2.6±1.3	2.8±0.9	3±1.3
audiotact. 1 (Tactile signal is **$\sin^2$**)	3.2±1.9	3.1±2.2	2.0±2.9	2.8±2.9	3.0±2.6	3.5±2.6
audiotact. 2 (tactile signal is **sin 50 Hz**)	3.2±1.2	2.8±1.2	2.2±2.1	2.5±1.4	2.5±2.6	2.5±1.5

(Fig. 5). This tendency is also observed for comfort ratings, but also for overall quality ratings as a smaller effect. The tactile stimulus sin 50 Hz gives particularly very good confirmation suitability ratings, if it is combined with auditory signals a, d or f which have high frequency components.

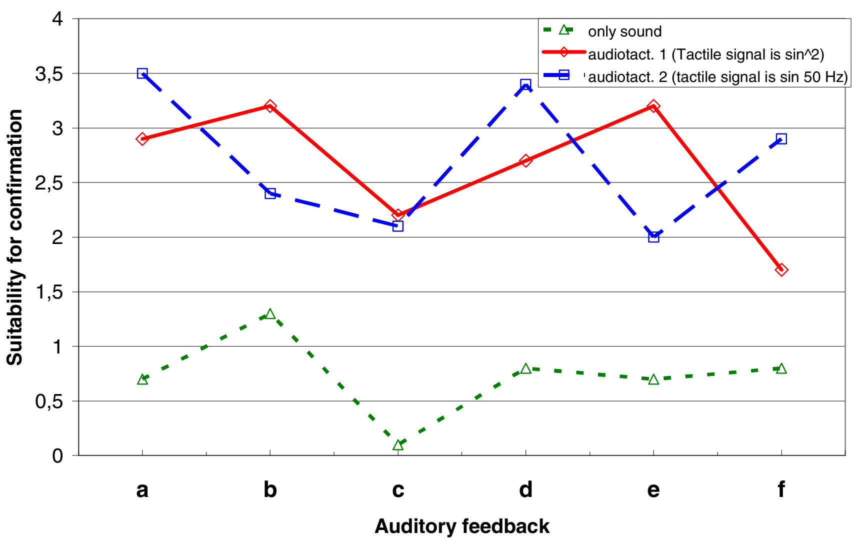


Fig. 5. Confirmation suitability ratings for audio only and auditoctile feedback conditions

3 General Discussion and Conclusions

The results of this study show the advantage of tactile feedback in both perceptual quality and error rate for a number-dialing task compared to no feedback. The results indicate that completion time may not be a very good way to measure performance. Similar effects are also observed for the auditory feedback. Auditory and tactile feedbacks in touch screens make user experiences more satisfying than no feedback. The results of the audiotactile experiments show that if both modalities are combined, there are synergy effects. The tactile signal can improve the audio only ratings and almost all ratings get better.

In this study, the number of participants is small. Thus further experiments are necessary to investigate those hypotheses. Some further experiments are planned with higher amount of stimulus variety.

References

1. Chang, A., O'Sullivan, C.: Audio-Haptic Feedback in Mobile Phones. In: Proc. of the CHI 2005, Portland, USA (2005)
2. Tikka, V., Laitinen, P.: Designing haptic feedback for touch display: Experimental study of perceived intensity and integration of haptic and audio. In: McGookin, D., Brewster, S. (eds.) HAID 2006. LNCS, vol. 4129, pp. 36–44. Springer, Heidelberg (2006)
3. Hoggan, E., Brewster, S.A., Johnston, J.: Investigating the effectiveness of tactile feedback for mobile touchscreens. In: Proc. of the twenty-sixth annual SIGCHI conference on Human factors in computing systems, Florence, Italy (2008)
4. Doerrer, C., Werthschuetzky, R.: Simulating Push-Buttons Using a Haptic Display – Requirements on Force Resolution and Force-Displacement Curve. In: Proc. of EuroHaptics, Edinburgh (2002)
5. Shimoga, K.B.: A survey of perceptual feedback issues in dexterous telemanipulation. II. Finger touch feedback. In: Proc. of the IEEE Virtual Reality Annual International Symposium (1993)
6. Poupyrev, I., Maruyama, S., Rekimoto, J.: Ambient Touch: Designing Tactile Interfaces for Handheld Devices. In: Proc. of the 15th annual ACM symposium on User interface software and technology, Paris, France (2002)
7. Rosenberg, L.B., Riegel, J.R.: Haptic Feedback for Touchpads and other Touch Controls, United States Patent 7, 148, 875 B2 (2006)
8. Hayward, V., Alarcon, R., Rosenberg, L.B.: Haptic Pads for use with user-interface devices, United States Patent 7, 336, 266 B2 (2008)
9. Ling, S.-H.W., Chang, C.-C., Liao, W.-C., Lin, W.-C.: Method and Apparatus of Electrotactile Panel with Pointing System (2007)
10. Kaaresoja, T., Hemanus, J.: Mobile Phone Using Tactile Icons, United States Patent 6, 963, 762 B2 (2005)
11. Kim, S.H., Yang, Y.S., Lee, J.H.: Tactile and Visual Display Device, United States Patent Application, 2008/0129705 A1 (2008)
12. Nunokawa, K., et al.: Information Transmission Apparatus, Information Transmission Method, and Monitoring Apparatus, United States Patent, 7, 327, 277 B2 (2008)
13. Connell, I.W.: Error analysis of ticket vending machines: comparing analytic and empirical data. Ergonomics 41(7), 927–961 (1998)
14. Rogers, W.A., Gilbert, D.K., Cabrera, E.F.: An analysis of automatic teller machine usage by older adults: a structured interview approach. Applied Ergonomics 28, 173–180 (1997)
15. Altinsoy, E.: Auditory-Tactile Interaction in Virtual Environments. Shaker Verlag, Germany (2006)