SONIFICATION SOLUTIONS FOR BODY MOVEMENTS IN REHABILITATION OF LOCOMOTOR DISORDERS

Johann P. Tissberger

Buchholzer Str. 41
D-09456 Annaberg-Buchholz, Germany
info@soundinform.de

György Wersényi

Széchenyi István University,
H-9026, Győr, Egyetem tér 1., Hungary
wersenyi@sze.hu

ABSTRACT

One of the recent fields of sonification focuses on the sonification of body movements in sports or rehabilitation. This is usually some kind of monitoring of real-time measurement data and auditory feedback for the patient. This paper presents two sonification approaches in medicine: a balancing coordination system and a robot for moving the legs after serious injuries of the lower body parts. These two systems are evaluated and compared based on the method of sonification, and transmission and analysis of the auditory information. Finally, a supposed method for using musical notes and measures is presented, and a selection method for the length of sonification based on the initial time interval is suggested.

1. INTRODUCTION

Sonification is a complex process for designing sounds and auditory environments in order to sonify data that is usually represented by visual means. This paper focuses on two different approaches on the filed of body movements, mainly rehabilitation aims.

Locomotor movement is when a person actually moves from one place to another and non-locomotor movement is moving on the spot without going anywhere. Locomotor movements are walking, running, swimming, flying etc. On the other hand, non-locomotor movements are:

- Twisting - the rotation of a selected body part around its long axis,
- Bending - moving a joint,
- Swaying - fluidly and gradually shifting the center of gravity from one body part to another,
- Stretching - moving body parts away from the center of gravity,
- Turning - rotating the body along the long axis,
- Swinging - rhythmical, smooth motion of a body part resembling a pendulum.

In our cases, one sonification approach was to develop auditory feedback for balancing problems (swaying), and walking disorders. After a short introduction of the method of analysis (based on the Morse code and the Geiger counter) the information transmission and evaluation of the two sonifications will be presented. At the end, a method is proposed for an easy selection of sonification intervals.

This pdf document contains embedded sound files in wave format. Some PDF readers may not be able to open and play back them without an external player. The functionality and compatibility for Adobe Acrobat 6 (or later) was tested using Adobe Acrobat 9.

2. BACKGROUND OF ANALYSIS

Sonification has a long history, although the name is newly developed. Sonification as a method for exploration of data and scientific modelling is a current and ongoing field of research [1-4]. The goal of this can be the transmission of acoustical information (AIT) and/or the analysis and evaluation of the acoustical information (AIA). In the simplest cases sonification can be the ticking of a clock or chiming the bells, as sonification of (passing) time. Similarly, the Morse codes or the clacking of a Geiger counter are basic sonification methods that makes measurement data audible and thus, possible to have constant and real-time observation of the results over auditory feedback. Table 1 shows an overview and simple comparison between these two basic sonifications. This kind of simple parametric overview is useful to compare other sonification methods and may help us to optimize the sonification procedure.

These aspects can be extended but the three main are: serial or parallel listening, method of sonification, and transmission rate of the information. These are not independent and effective optimization of the sonification can be made if the effects and interactions are known. One of the main problems is the parallel (concurrent) presentation of multidimensional data that allows higher transmission rate but temporal resolution or depth of the results may have to be decreased. Furthermore, in case of a real-time monitoring of measured data, only results of simultaneous measurement can be used for parallel sonification (AIT). In case of data analysis, real-time evaluation may not be required. Instead of the exact temporal representation of data, the temporal compression or off-line editing of parallel data structures can be analyzed and evaluated more efficiently (AIA).

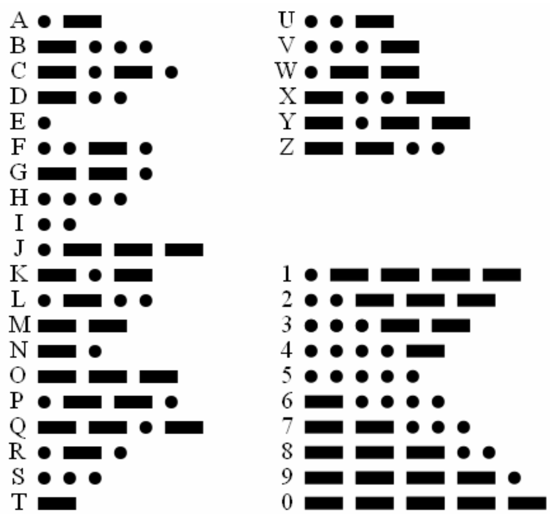

Figure 1: The 26 letters and 10 digits of the commonly used Morse code that can be visualized or sonified.

Parameters	**Morse code**	**Geiger counter**
Field of interest	Telecommunication	Measurement, engineering
Goal of sonification	Acoustical information transmission	Real-time auditory feedback of measured data
Rule of sonification	The smallest information unit has to be translated into sound(samples)	Measured values (signal levels) have to be translated into sound(levels)
Method of sonification	Serial, combination of basic signals	Serial, pulse-density modulation
Sound design	Pure tone impulses (short and long) with different breaks	Electro-mechanic clacking
Decoding of sonification	A-priori learning of the signals (alphabet) needed	No a-priori learning needed
Transmission rate of information	About 5-times of regular speech	Irrelevant

Table 1. Comparison of two classical sonifications.

It is very challenging to try to formalize and regularize universal methods for sonification and for sonification „language". In case of Morse, the smallest information is one letter (vocal), and the alphabet contains 26 Roman letters and ten numbers that have to be learned, and the information transmission is serial. In real life applications and tasks methods and rules differ and optimization depends on the smallest amount of information per time unit. An optimal sonification may not need a-priori knowledge and learning phases. Transmission rate of information is not unlimited in AIT and is hard to determine in AIA, because it is not known how many simultaneous data can be presented and what kind of temporal compression will be needed. Furthermore, data transmission rate as well as the speed of sonification can be a variable. The decoding capacity of the brain and the hearing system depends on signal quality and signal parameters and is based on psychoacoustic observations. The main parameters are usually temporal and spectral resolution, spatial directions and dimension, playback methods etc. [5].

3. SONIFICATION OF BODY MOVEMENT

Medical applications of sonification are recently in interest [6-12]. In this section we present two German projects called the „GKS" (Gleichgewichts-Koordinations-System, Balancing-Coordination-System) and the „Gangroboter" (Walking Robot). Both were designed for a real-time auditory feedback for the patient during therapy.

The GKS primarily operates visually. It displays the incorrect body posture in a standing position and the unbalanced distribution of the body mass on the legs. The centroid of the body is marked with a red dot and its movement can be followed real-time on a screen. In optimal case this red dot is in the middle of a cross-hair. The sonification task was to extend this feedback with auditory information as well. Unbalanced and not optimal situations cause a warning signal. Reasons for a warning signal are:

- wrong direction of body posture,
- the extent of unbalanced position, and
- changes in the balancing procedure.

Furthermore, the changing of the centroid in the horizontal plane (2D) can be reproduced by a spatialized (one-dimensional stereo) playback system. In order to do this, left-right asymmetries are presented left-right respectively, while front-back asymmetries via pitch changes up and down (within one octave). The sound is continuous, monotic and is presented in the middle of the virtual sound scape by default. If the extent of the unbalanced position is increasing, the loudness of the signal will be also increased. There is a maximal threshold for loudness level and limit of the unbalanced position.

The signal was chosen to be the sound of the hornet (bumblebee) that can be well localized and small changes in pitch and level can be detected easily. The sound was recorded in a natural environment. Learning and adaptation time to this sonification is very quick. The transmission rate is irrelevant, because the sonification is serial, real-time and continuous.

The walking robot is a Swiss made robot that helps patients paralyzed or restricted below the waistline to re-learn walking for diagnostic purposes and therapy. The mechanic system moves the legs of the patient and monitors the motion activity (of the muscles) at the same time. During sonification, a reference sound of the robot movement had to be created and the task of the patient was to reproduce it with his own body movement. The sonified movement process was synchronized rhythmically and force of the robot and of the muscles could be monitored and compared.
The sonification applies two-channel transmission on a stereo headphone where left channel is the sonified data of the mechanical force of the robot (reference signal) and right channel is the sonification of the measured force activity of the muscles in the legs. The goal is to adjust the latest in order to be identical to the reference signal. Sound level is proportional to the force of the robot and the muscle respectively. The functional reference sound and adjusted sound are superposed onto background music. Additional music can be motivating and entertaining, its rhythm can be proportional and adjusted to the rhythm of the movement (walking speed etc.). See Figure 4 for a visual interpretation.

Patients responded quickly and easily to this sonification method in the preliminary tests. During a training phase, only one leg is activated. Proportional to the force of the legs the level of the background music is also amplified in order to avoid masking effects of music, reference signal and feedback. Similarly to the “GKS”, transmission of information is serial, continuous and transmission rate is irrelevant. The development of the system includes real-life testing with patients and optimal synchronization of music and controlling of the robot. Furthermore, a simultaneous presentation of signals of both legs with or without reference sound is not yet implemented.

The idea of having rhythmically selected and adjusted background music seems to be a successful way for extending body movement sonification. However, selecting of the proper piece of music can be difficult for a correct embedding of other signals (masking effects). During this process, first, the most appropriate functional (reference) sounds have to be selected, followed by different music parts adjusted to different walking speeds. This includes first of all rhythmical parameters, but melody, harmony and instrumentation can be also taken into account. For another therapy approach for increasing functionality of the legs is the motion of cycling recommended.

A third sonification concept also includes music background, where the twang of a bass guitar serves for timing (measures). One datasample is 100-ms corresponding to one day data. One week is 1/4, one month is 4/4. One year makes about 37 sec of sonification. Figure 2 shows an example of dataset “a” and “b” together, where a spectral scale (notes) corresponds to the value of the data. For dataset “a” it is *c1, e1, g1, aisz1, c2* whilst for dataset “b” it is *e2, g2, aisz2, c3, e3*. The scale has five steps: if the data value is small, only *c1/e2* is played back (day 2), when the data value is big, all five musical notes sound together. Dataset “c” and “d” have the same pitch as “a” and “b”, but “c” is sawtooth and “d” is impulse. Figure 3 shows soundset “a” in a one-month period.

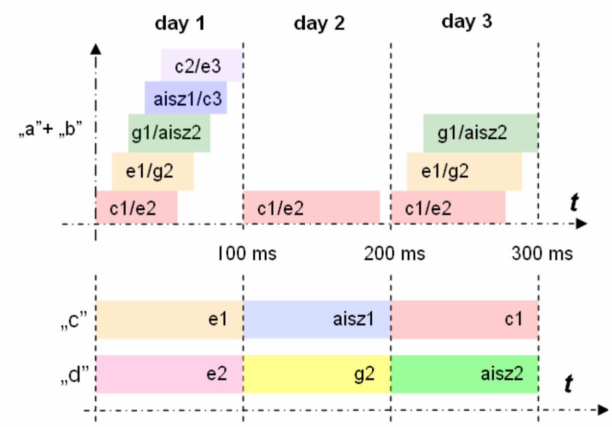

Figure 2: Sonification procedure for datasets “a+b”, “c” and “d”. Musical notes correspond to different values of the dataset on a five-step scale. Using different notes, different datasets could sound together. See Figure 3 for dataset “a” only in a one-month period.

These datasets can be any kind of data meant for sonification. The idea is to use a limited number scale (in this case five) corresponding to the value of the data to be sonified. Furthermore, the question is whether parallel presentation of datasets using different notes can be detected easily or not, depending on presentation speed as well. All these sonification methods may include musical background for pacing and for keeping correct timing.

4. SONIFICATION TIME FRAMES

It is an interesting question to find out how long the sonification should be depending on the time interval of the sonified data (compression rate). It seems to be reasonable to have a sonification (listening) time of about 1-6 minutes. Table 2 shows a proposed method for estimating time intervals. It was assumed that one elementary sound sample used for the sonification is 100-ms resulting in a data transfer rate of 600 samples/minute. This elementary sound sample can be detected by the hearing system, but a continuous presentation can mask information. It seems to be a good choice not to have more than about 4000 samples in one sonification period (partitioning for 6 to 7-minute periods). Reduction of the sonification time-slot can be made by halving the observation time or by doubling the presentation speed. In case of longer sonifications (over 3 minutes) it is also recommended to embed the sonified data into musical background (that matches rhythmically).
If we choose 100 ms as the elementary sample, one hour of data needs 3600 elementary samples, that is 6 minutes. A whole day of 86400 would exceed our limit, so in this case we need to compress data and one elementary sample will represent one minute etc.
If one 100-ms sample represents one year only, a reasonable sonification can be made over 1000 years. Dividing one year to 52 weeks, or one day for 12 sub-periods of 2 hours, would result in a better timeframe than using a simple one-by-one mapping of the elementary sample. Length of a 10-year period

can be from 52 seconds up to 6 minutes corresponding to the time resolution. A decision can be made based on the actual length of the data to be sonified: in case of 40-60 years a shorter period is recommended.

5. CONCLUSIONS

This short paper overviewed which parameters can be used for basic comparison and evaluation of different sonification methods. The three main selected parameters were: serial or parallel, method of sonification and transmission rate of the information. Two sonification approaches were presented on the field of body movement therapy. Both the balancing-system as well as the walking robot performed well in real-life situations with patients. The idea of having sonified data signals superimposed over background music can be a straightforward method that makes the training and rehabilitation process more entertaining and also gives the possibility to control rhythmical considerations during the process.

6. REFERENCES

[1] B. N. Walker, and M. A. Nees, “Theory of Sonification,” in T. Hermann, A. Hunt, and J. Neuhoff (Eds.), *Handbook of Sonification* (pp.TBD), New York, Academic Press, 2011

[2] T. L. Bonebright, N. E. Miner, T. E. Goldsmith, and T. P. Caudell, ”Data collection and analysis techniques for evaluating the perceptual qualities of auditory stimuli,” ACM *Transactions on Applied Perception (TAP)*, vol. 2, no. 4, October 2005, pp. 505 – 516.

[3] T. Herrmann, ”Taxonomy and Definitions for Sonification and Auditory Display,” in Proc. of the 14th International Conference on Auditory Display (ICAD2008), Paris, France, 2008.

[4] R. Kramme, K.-P. Hoffmann, and R. S. Pozos (Eds.), *Springer Handbook of Medical Technology*, Boston, 2011.

[5] J. Blauert, *Spatial Hearing - Revised Edition: The Psychophysics of Human Sound Localization*, The MIT Press, 1996.

[6] N. Schaffert, K. Mattes, and A. O. Effenberg, ”A sound design for the purposes of movement optimisation in elite sport (using the example of rowing),” in Proc. of the 15th International Conference on Auditory Display (ICAD2009), Copenhagen, Denmark, 2009.

[7] K. Vogt, D. Pirró, I. Kobenz, R. Höldrich, and G. Eckel, ”Physiosonic - movement sonification as auditory feedback” in Proc. of the 15th International Conference on Auditory Display (ICAD2009), Copenhagen, Denmark, 2009.

[8] O. Höner, T. Hermann, and C. Grunow, “Sonification of Group Behavior for Analysis and Training of Sports Tactics”, in T. Hermann, A. Hunt (Eds.), in Proc. of the International Workshop on Interactive Sonification, Bielefeld, 2004.

[9] T. Hermann, O. Höner, and H. Ritter, “AcouMotion – An Interactive Sonification System for Acoustic Motion Control”, in S. Gibet et al. (Eds.), gesture in Human-Computer Onteraction nd Simulation, Lecture Notes in Artificial Intelligence, Vol. 3881, Berlin, Heidelberg: Springer, 2006.

[10] A. Tsukahara, Y. Hasegawa, and Y. Sankai, “Standing-Up Motion Support for Paraplegic Patient with Robot Suit HAL,” in Proc.of the IEEE 11th International Conference on Rehabilitation Robotics, Kyoto, Japan, 2009.

[11] J. S. Sulzer, R. A. Roiz, M. A. Peshkin, and J. L. Patton, ”A Highly Backdrivable, Lightweight Knee Actuator for Investigating Gait in Stroke,” *IEEE Transactions on Robotics*, vol. 25, no. 3, pp. 539 – 548, 2009.

[12] P. Terrier, and O. Deriaz, “Kinematic variability, fractal dynamics and local dynamic stability of treadmill walking,” *Journal of NeuroEngineering and Rehabilitation*, 2011, 8:12, 24 February 2011.

7. EMBEDDED SOUNDFILES

For listening to the soundfiles with detailed description see end of the document. Use Adobe Acrobat 6 or later if possible. Adobe Readers support only mp3 embedded files and you may need an external player for wave files. For external player use e.g. the “VLC player” for playback.

Second	**Minute**	**Hour**	**Day**	**Month (30 days)**	**Year**	**10 years**	**100 years**	**1000 years**	**Time period of sonification**
100 ms *1	60	**3600**	~~86400~~						360 s / hour
	100 ms*1	60	**1440**	~~43200~~					144 s / day
		100ms*1	24	**720**	~~8640~~				72 s / month
			100ms*1 100ms*12	30 30	**360** **4320**	**3600** ~~43200~~			36 s / 1 year 360 s /10 years 432 s/1 year
			100 ms / 7 = 14,28 ms		52	**520**	~~12000~~		52 s/ 10 years
				100ms*1	12	120	**1200**	~~12000~~	120 s/ 100 years
					100ms*1	10	100	**1000**	100 s/ 1000 years

Table 2. Proposed time intervals and compression for sonification.

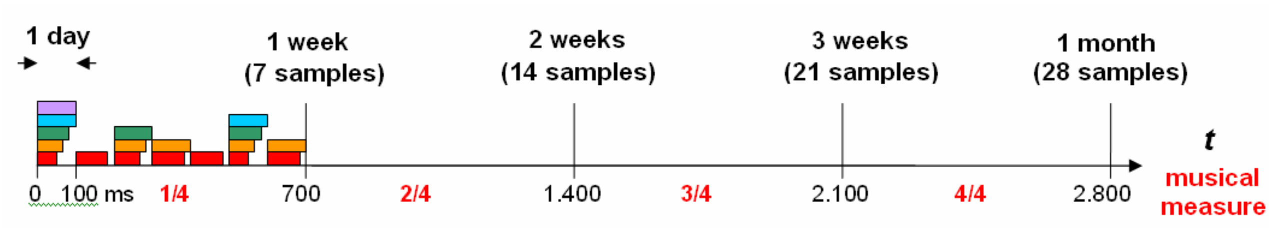

Figure 3: Dataset "a" for a one-month period including musical measure and notes (*c1*, *e1*, *g1*, *aisz1*, *c2*).

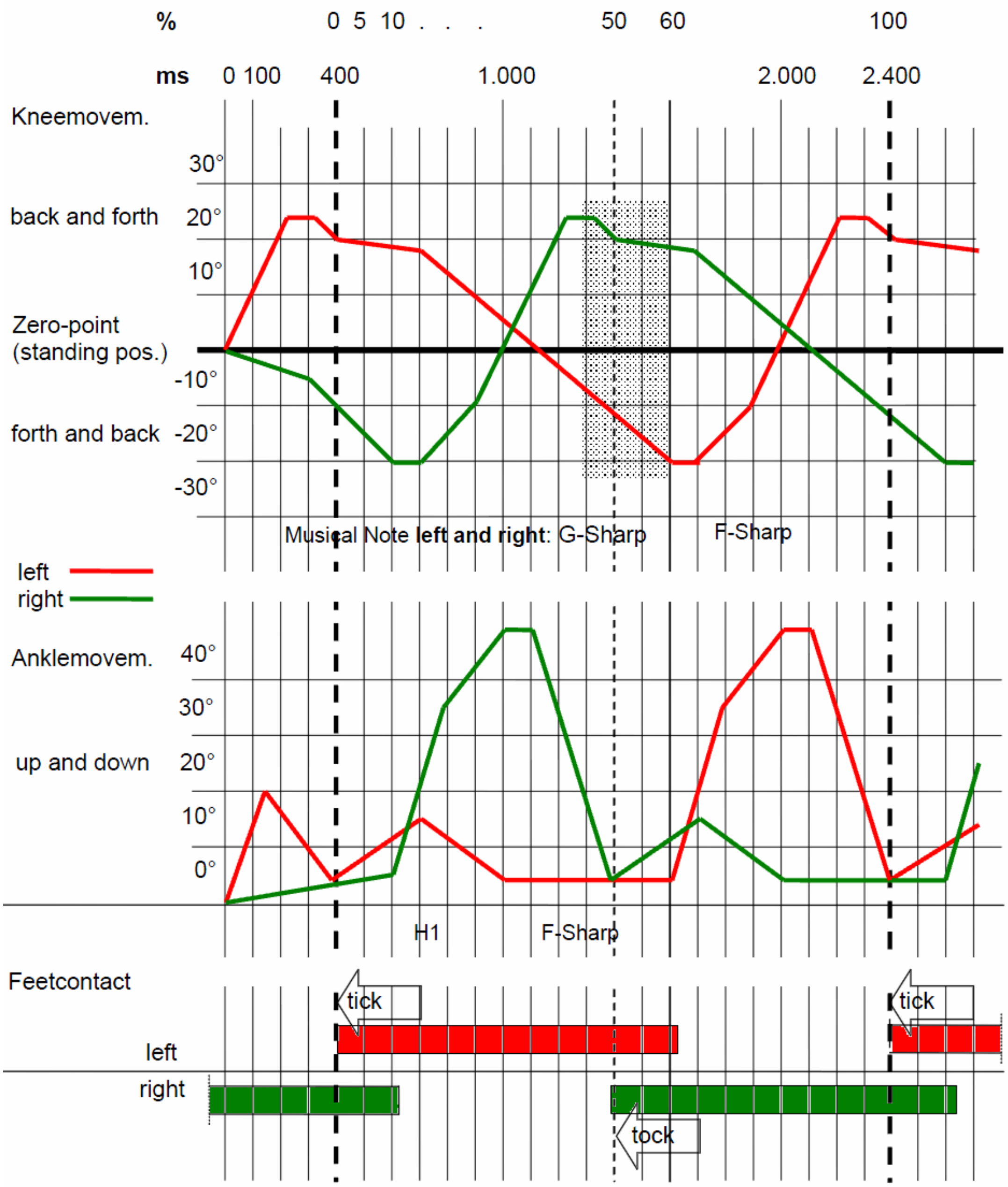

Figure 4: Sonification of the walking robot task.

FILE NR 1.

The "GKS" system using two-channel 2D-mapping (left-right and up-down) corresponding to left-right displacement and changing in pitch. Video can be watched using VLC player.

FILE NR 2.

The walking robot (Gangroboter) sonification including musical background and two-channel data sonification (robot force and muscle force to be compared).

FILES NR 3-8.

FILE NR 3. Dataset "a" with five steps of musical scale corresponding to Figures 2 and 3.

FILE NR 4. Dataset "b" with five steps of musical scale corresponding to Figures 2 and 3.

FILE NR 5. Dataset "c" with five steps of musical scale corresponding to Figures 2 and 3.

FILE NR 6. Dataset "d" with five steps of musical scale corresponding to Figures 2 and 3.

FILE NR 7. Dataset "a+c+d" with five steps of musical scale corresponding to Figures 2 and 3.

FILE NR 8. Complete sonification of datasets presented parallel with musical background (measures)