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Research of Medical Imagine Sonification

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Abstract: Among all of the sonification research areas, multi-dimensional mapping of continuous data becomes the hotspot of current research as it is difficult to solve. Sonification research on one-dimensional data or discrete signals are currently drawing more attention than the other research areas. For the multi-dimensional signal, the choice of mapping variable should be very careful due to its need to find a suitable intermediate mapping variables. There are relatively few people involved in the in this area and hence very little literature can be found. As the research object, this study chooses the two-dimensional signal and takes medical images as example, choosing gray-scale, gradient and camber as the intermediate mapping variables, to research the sonification of two-dimensional orthopedic medical images.

Key words: Sonification, medical images, mapping variables

INTRODUCTION

As an emerging research area, sonification researching (Hussein *et al*., 2009) are considerably active in U.S., Japan, U.K., Brazil and HK of China, with a focus on sonification perception, development of sonification display and platform, sonification design and application as well as applicable analysis and evaluation (Massimino, 1992). The framework of sonification theory is already built, fundamental soft/hardware technology needed (real-time voice parameterizing) are also available. Major problems which are mainly related to the psychological procedure of sonification perception of current researches, along with unsound basic theory of data mapping design, causing the developed system couldn't meet the users' expectation in terms of usability (Kramer, 1994). From domestic and international perspective, mainstream researches are either obviously psychology-oriented sonification perception, or case study of application system design and implementation, or software and algorithm-oriented with a focus on sonification system SDK and development (Kramer *et al*., 2008). Sonification researching is tightly interwoven with signal processing, software technology, psychology, ergonomics (Zhang and Cen, 2008) and hence, a highly multidisciplinary area which is in need of multidisciplinary cooperation. However the researches from these disciplines are distinctly disconnected and unable to fuse seamlessly. Limited system availability and the design of sonification which is in the desperate need of guiding theory, slow down the sonification application development. Among all of these restrictions, mapping of multi-dimensional continuous data should be the foremost to be considered. Most of current researches are focused on one-dimensional or discrete data sonification, multi-dimensional data sonification are in its initial stage temporarily and there are few academic attention paid to this area. The solving of this problem would lay a solid foundation and establish useful criteria for advanced sonification application.

IMAGINE SONIFICATION

Appropriate immediate mapping variable should be carefully chosen for multi-dimensional data sonification. Considering that multi-dimensional data sonification can blaze a new trail in imagine, texture, 3D object recognition and high-dimension field researching, although there are few related work in this area, Cabrera and Ferguson (2007) said multi-dimensional data sonification are preferred to multi-dimensional point data in terms of practical value. As this study focused on two-dimensional signal, the research is demonstrated with medical imagine and refer to this as imagine sonification.

The imagine sonification is representing the immediate variables of an imagine in an audible way and then detecting the information can not be dug out in visual channel through the variance of voice, or transmitting the complementary or redundant information to increasing the channel bandwidth and robustness through voice signal for deeper understanding of the information carried by imagine. It can be apply to data mining, pattern recognition, imagine analysis, providing a brand-new method to advancing imagine processing.

The principle of imagine sonification (Xu *et al*., 2004) is that, with a high temporal resolution, human ear is very

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sensitive to the variance of signal, especially for frequency signal, to which resolution can be an order of magnitude higher than visual signal. As a direct result, human discrimination to voice signal should be higher while representing the variable signal with both visual and acoustic way. The key of imagine sonification is searching for appropriate immediate mapping variable which leads to researching on mapping algorithm and its effectiveness. Imagine sonification is different from the frequently-mentioned pattern recognition. In the pattern recognition, the particular pattern to which input variables subordinated to, or possibility of such a subordination relationship is given by classification networks through analyzing some modeling parameters. In the imagine sonification design, However, the final judgment was made by the reaction to signal through the analysis of voice which is conducted by human brain itself. This judgment was made within the human body, rather than computer. So it can be applied to pattern recognition as a novel method which is easier than before and at the same time more effective.

In order to make the research more precisely aimed at imagine sonification, the research was built upon medical imagines coming from orthopedics. This is because:

- The differences between objects and background in an orthopedic imagine was clear, so orthopedic imagines were very easy to differentiate and threshold value for binaryzation can be found easily
- Presenting colors on current displays will be subjected to color offset, causing orthopedic imagine distortion which can be improved through representing the signals by acoustic channel
- Human eyes can not focus on screen for too long, as the screen using visual channel as main channel for transferring information will surely lead to fatigue. Introducing acoustic channel can remit this visual channel long-time over-loaded situation. Work efficiency can be improved through using voice probe to off-load the visual channel
- The study hopes to leverage the variable human sensibility to different signals to unveil the natural essence of data, e.g. detecting the problems inside imagine through voice, these problems might not be found be human eyes or outright visually undetectable

MAPPING ALGORITHM BASED ON GRAY-SCALE

Gray-scale is the integral of light to time on sensitive devices. In the orthopedic x-ray imagine, gray-scale is stand for bone density. So, if we directly mapping the bone density to gray-scale, the variance of bone density is coordinated with the variance of coordinates, as shown in the Fig. 1. The left of Fig. 1 is a normal human bone, the right side is a human bone with abnormal density. We need an appropriate immediate variable for follow-up mapping work.

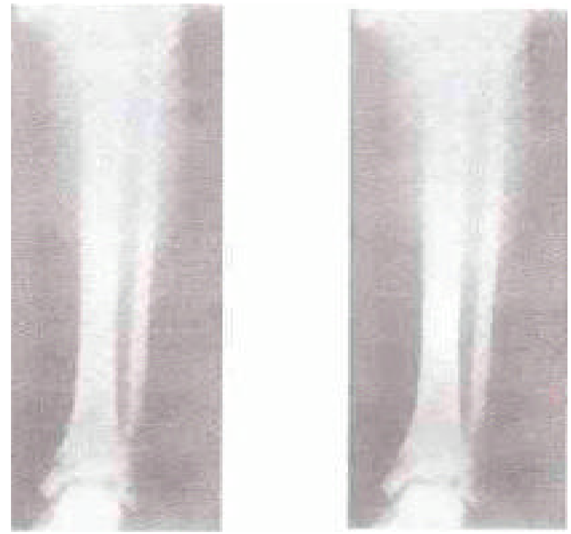

Fig. 1: Normal human bone (left) and abnormal human bone

Mapping algorithm 1 is transforming 2D data into 1D data. The gray-scale of imagine was transforming into 1D, from top to bottom and from left to right and the 1D data can be processing by sonification mapping method for 1D continuous signal after that. From the theoretical perspective, this kind of transform seems feasible but this operation turns into another story from the practical perspective. Imagine is a gigantic matrix whether in terms of row-size or column-size, for instance, an imagine with 100×100 pixels would be transformed into an 1D array with over 10000 elements. Assumes that every single element would produce sound of 0.001 second, the whole imagine would be transformed into 10 second sound. Considering that average imagine size is far bigger than that, this transform is not feasible.

Mapping algorithm 2 is calculating the average of every single row of gray-scale and doing sonification mapping the data according to the average. In this mapping algorithm, every single point of every single row will be normalized as per its gray-scale and then pass the normalized gray-scale to parameter mapping procedure. The flaw of this algorithm is that, in orthopedic imagines, gray-scale distribution of human bone is what we really concerned, rather than background distribution but useless background data is involved in the mapping

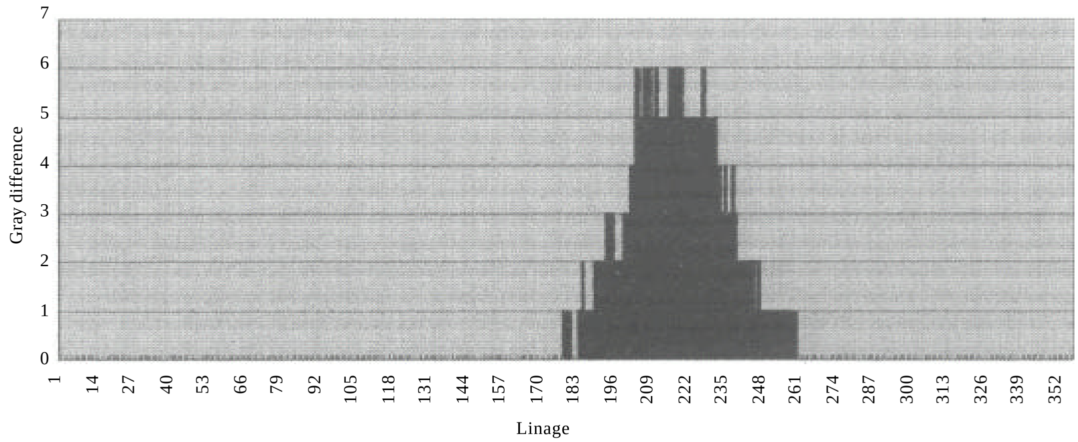

Fig. 2: Gray-scale difference of two imagine, obtained from row-major statistic algorithm

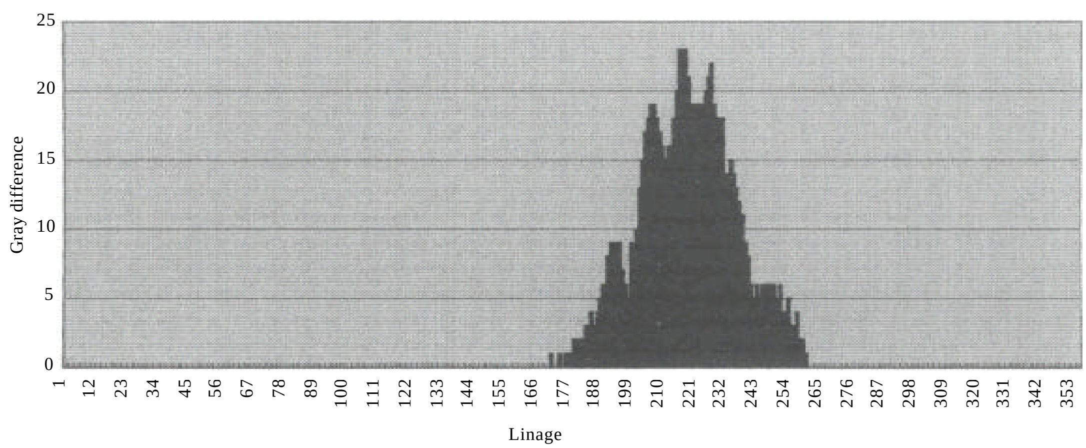

Fig. 3: Gray-scale difference calculated by row-major gray-scale enhanced algorithm

procedure, because the mapping algorithm 1 and 2 are just mapping the data to acoustic channel indiscriminatingly. In order to prevent the valuable information being swamped in the background data flow, trade-off should be made while sampling the gray-scale. Row-major statistic algorithm is shown in Fig. 2.

Mapping algorithm 3 is calculating the gray-scale in the first place and then setting the threshold value (average gray-scale×(background area/bone area)) according to the ratio of bone area to background area in the image, discarding the sub-threshold point (these points are regarded as background), carrying the rest points to the final analysis procedure. We call this row-major gray-scale enhanced algorithm, as shown in Fig. 3.

It can be seen from Fig. 3 clearly that algorithm 3 enhanced the different part of an imagine while preserving the original information, the differential between these two imagine increased from 5 to 23. This mapping procedure is obviously more discriminating. If the sonification pattern of normal human bone is already known in the gray-scale mapping procedure and another human bone produced another pattern different from the normal pattern, then this orthopedic imagine can be asserted is abnormal. This gray-scale mapping procedure is useful for detecting the abnormal bone density. By comparing the row-major statistic sonification experiment results of the two imagine from Fig. 1, the study shows there is distinction among these sonification patterns.

MAPPING ALGORITHM BASED ON GRADIENT AND CAMBER VARIABLES

Camber variables are sensitive when it comes to detecting the imagine signal jumps. The edge of human bone provides plenty of information, gray-scale values always drastically jump at the edge of human bone and background. Extracting these information out of the edges can be valuable for the work. Assumes that there is an fractured ulna, for normal ulna, the jump of gray-scale values only occurs at the right of left edge of bone area, as for the fractured ulna, the jump will appear twice more for the fractured section. This is to say that imagine of fractured bone is different from imagine of normal bone in terms of gradient. The imagine gradient can be calculated by means of this phenomenon. Similar with the three types of gray-scale mapping algorithms, the gradient mapping algorithm can also be classified into three types, mapping 2D to 1D algorithm, row-major gradient algorithm, row-major gradient enhanced algorithm. These gradient algorithms are not worth detailed describing since the gradient mapping procedure is almost the same with gray-scale mapping algorithms, except that gradient algorithms is calculating pixel grad scale and its differentiate to surrounding pixels. We have found it effective for detecting abnormal bone density and bone fracture.

Camber variables are defined during the research phase. The geometric shape can make huge impact while interpreting the orthopedic imagines, as a result, shape should be preserved as much as possible during the processing procedure. For the most part, we can represent an object using its edge, the points reside at the edge will help to distinguish different shape if positions of those points are known up front. Freeman chain code which was first proposed by H. Freeman is chosen to distinguish different geometric shapes. The essence of chain code lies in a series of pointer, for every pixel in the imagine, there are eight separate pointers correlated to eight surrounding pixels of it, the chain code starts at a segment of curve and then move alone the directions of successive segments to produce an array of pointers representing the corresponding segments. This chain code is able to represent arbitrary cure or closed line. The chain code of the edges is defined as camber and further combined with improved mapping algorithm to enable problem detection while preserving the homogeneity of period.

Possible gradients can't be enumerated in analogy imagine. In the digital imagine, however, the work continue to use the chain code to solve this problem. Considering eight separate area, there are eight distinct possibilities for first-order pointer, 8×7 = 56 distinct possibilities for second-order pointer, 8×7×7-7 = 384 possibilities for third-order pointer and so forth. After frequency statistics of sundry imagines, we can plot first-order, second-order, third-order gradient bar charts which include statistic features of shapes for corresponding orthopedic imagines. The gradient bar charts vary greatly among imagines, this is the fountain to leverage the variances of gradients to identify the possible change of geometric shape.

COMPARISON OF IMAGINE SONIFICATION MAPPING ALGORITHMS

The sections presented above have described multiple imagine sonification mapping algorithms based on different immediate mapping variables, including gray-scale, gradient and camber, this section serves as a comprehensive comparison of these mapping algorithms, shown as Table 1.

Table 1: Comparison of mapping algorithms

Immediate mapping variables	Mapping algorithms	Statistical variables	Sonification standard level (duration equivalence)
Gray-scale	2D convert to 1D	Pixel's gray-scale	bad (can't be actual application)
	Row gray-scale count	Pixel's row gray-scale mean	common (limited to the image size)
	Enhance the row gray-scale count	Pixel's row gray-scale mean which above the threshold	Common (limited to the image size)
Gradient	2D convert to 1D	Gradient between the pixels	Bad (can't be actual application)
	Row gradient count	Row gradient mean between the pixels	common (limited to the image size)
	Enhance row gradient count	Row gradient mean between the pixels which above the threshold	Common (limited to the image size)
Camber	Chain code mapping	Chain code of image contour	Common (limited to the image complexity)
	First-order camber mapping	first-order statistical properties of chain code	Good (all images' sonification voice is isometric)
	Second-order, high-order camber mapping	Second-order, high-order statistical properties of chain code	Good (all images' sonification voice is isometric)

Complexity of the algorithm	Detect the content of orthopaedic images	Other uses of the algorithm
Simple	Bone density anomaly, fracture	No
Common	Bone density anomaly, fracture	
Complex	Bone density anomaly	
Simple	Fracture	No
Common	Fracture	
Complex	Fracture	
Complex	Fracture, bone deformity	It can be used for the construction of recognition
Complex	Fracture, bone deformity	Vector space for character recognition
Complex	Fracture, bone deformity	

CONCLUSION

Non-voice signals could have played more acting role in the human-computer interaction, based on the corresponding application researches. Discrete signals, whether structured or unstructured, can be represented well in this way and normative guiding design principles have been established. As for continuous signals, multiple-dimensional mapping is easy but appropriate immediate mapping variables should be found since multiple-dimensional signals correspond to different information source. Consequently, the crucial part the whole sonification procedure is that multiple mapping algorithm should be carefully considered for extracting useful information. This study chooses two-dimensional signals as researching object and exemplifies the whole processing procedure by medical imagine. As the results have shown, imagine sonification could harness the power of human acouesthesia to trigger the intrinsic and spontaneous perception of characters of data. However, mapping modes are still deficient, some mapping steps need to be improved and enhanced further, since this study is just an pilot study.

Due to the fact that our mapping algorithm presented herein just focus on time-domain, we are in the hope of introducing more effective mapping algorithm in the future, such as frequency-domain technology. Sonification mapping by spectrum line produced by Fourier transformation can be taken into consideration, the reason is that once there are abrupt changes inside the imagines, high-frequency part of the spectrums will surely be enhanced, if we could control the sonification procedure according to frequency spectrums of different imagines, ideal results might be achieved. However, the characters produced by Fourier transformation takes its roots in the whole imagine, causing the situation that useful information is swamped by background dataflow. How to pre-process the picture without damage the useful information while still capable of confronting with more mapping problem emerging in the processing procedure? Is that possible to fuse all of the algorithm discussed above into one better algorithm? These issues will be left to future researchers.

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