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Musical Pattern Design Using Contour Icons

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ABSTRACT

This paper considers the use of Contour Icons in the design and implementation of musical patterns, for the purposes of detection and recognition. Research work had endeavoured to deliver musical patterns that were both distinct and memorable, and to this end a set of basic melodic shapes were introduced using a Sonification application called TrioSon that had been designed for the purpose.

Existing work in the field (such as that concerning Earcon design [1]) has considered the mechanisms by which patterns may be made distinctive, but it is argued that separate consideration must be given to the method of making such patterns memorable. This work suggests that while segregation and detection can best be facilitated by the individuality of a patterns rhythm [2] and [3], the retention (and hence future recognition) of a musical pattern is concerned more with its melodic range [4] and contour [5] and [6].

The detection and comprehension of musical patterns based around basic shapes (known as Contour Icons) was tested, within Sonifications of simple data sets generated using TrioSon. A set of test patterns based on such factors as tonality and key was used for control purposes, with Contour Icons being introduced in the second set of tests. Results suggest that significant improvement was made due to the use of Contour Icons, with further work focusing on the many possibilities that such a design framework would suggest.

1. INTRODUCTION

Sonification concerns the delivery of data and information using non-speech audio [7], and indeed many differing methods of such delivery have been considered. The speed at which stimuli can be detected by the auditory cortex (2ms for audio [8] compared to 100ms for vision), suggests that the delivery of information using Sonification could be far more efficient than with existing visual methods. Allied to this is the sensory independence of the hearing mechanism, allowing other (perhaps unassociated) tasks to be performed in tandem in a manner that is not possible using visual mechanisms.
Work undertaken during this research concerns the delivery of information using Sonification, specifically the most efficient means of detecting and comprehending musical patterns in a sequence. Using the TrioSon application (Figure 1), test subjects were asked to load in various data files of CSV (Comma Separated Values) format. The data from these files was then used as the basis of a Sonification, with input values being represented by musical patterns at output. By rendering these patterns relative to the original input data, a Sonification of the data set could be produced that would allow the user to detect which data variables occurred (and how often).

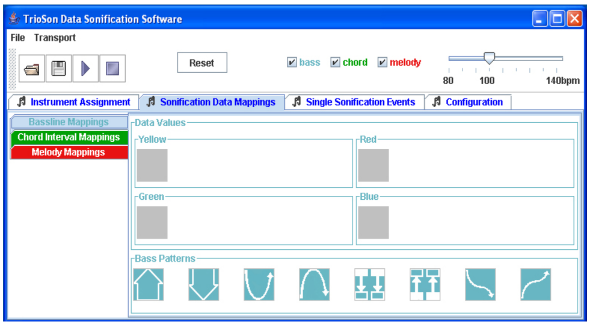

Figure 1. *TrioSon Sonification Application*

Each CSV file held lists of variables for specific parameters (such as favourite colour, film or book), with each parameter being sonified individually. Subjects were given a choice of 8 distinct musical patterns for each parameter, with each pattern being allocated to an individual variable in the data set (Figure 2).

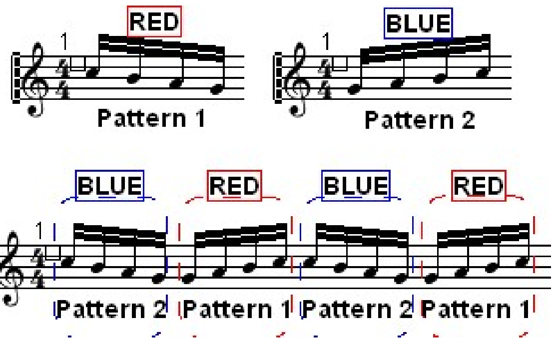

Figure 2. *Sonification of Patterns Representing the Colours Red and Blue*

Subjects were then asked to answer questions on parameters within the data sets (such as how many people like the colour green) by listening to the Sonification of that parameter. It was intended to observe how well patterns could be recognised and interpreted by the test subjects, with a view to designing the most effective set of patterns possible.

2. MUSICAL PATTERN DESIGN

Initial pattern design guidelines had been taken from those used in the design of Earcons [9], with particular focus being given to the rhythm of each pattern. By making the rhythm of each pattern as distinct and unique as possible, it was intended to create a set of patterns that could be discerned individually by all test subjects. Each pattern was constructed within an 8 note pattern template (Figure 3), which was intended to give the smallest possible resolution (1 semiquaver) deemed suitable for most listeners.

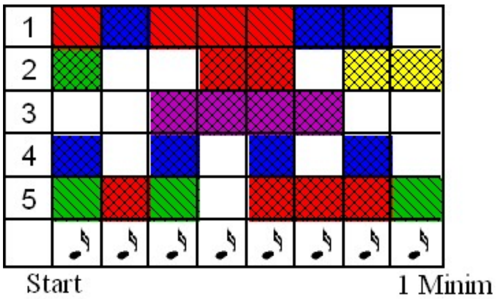

Figure 3. *Example Pattern Combinations using 8 Note Template*

The melody of each pattern was composed by its rhythm, again seeking to create the most distinct signature for each pattern as possible. Individual pattern timbres were considered, but as TrioSon outputs a standard Midi file (SMF) for multiple parameters it was decided that timbre would be used to signify parameter rather than variable.

Patterns had initially been assigned in a numerical manner (see Figure 4), with test subjects referencing each pattern purely by its index.

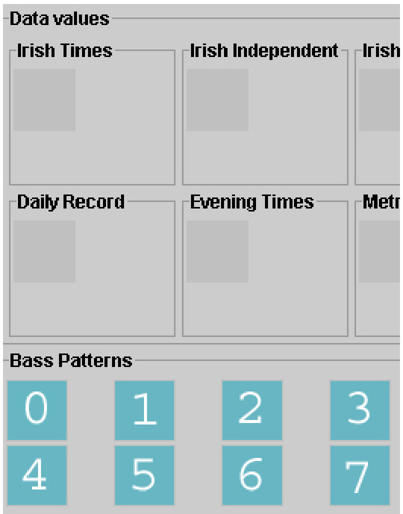

Figure 4. *Initial TrioSon Pattern Allocation Section*

It had been noticed during tests performed using these patterns that subjects had often become fatigued over time. It had also been observed that while subjects could detect individual patterns during a Sonification, they would often require multiple passes to recall which pattern was related to each variable. These observations suggested that test subjects were encountering difficulties in recalling specific patterns, and were subsequently often unable to match those patterns to their associated variables within the given time.

This problem was believed to be largely attributable to the requirement of performing several mental operations within the process of detection (Figure 5).

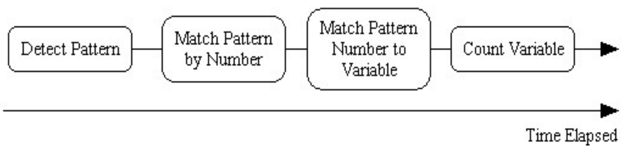

Figure 5. *High Level Representation of Pattern Matching Thought Process*

This numerical means of pattern definition had proven intellectually cumbersome, and some method of more effectively streamlining the process was desired (Figure 6). It was desired to provide the user with a more intuitive means of detecting patterns, in the hope that this would lead to a more efficient method of pattern detection and recognition.

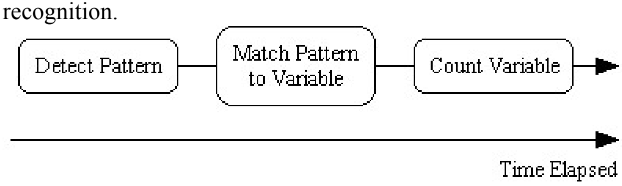

Figure 6. *High Level Representation of Idealised Pattern Matching Thought Process*

The specific problem of pattern matching concerned the means by which each test subject would most easily relate a specific pattern to its associated variable. The goal of any pattern design template was that hearing said patterns would immediately invoke recognition of the quantity represented. This facility was found to be present as a consequence of musical training, wherein practiced musicians could score basic representations of patterns prior to their detection and then simply label each pattern with its associated variable.

This situation was not ideal, in that it not only required the use of external visual materials (such as pen and paper) but also precluded the effective involvement of non-musicians. In order to provide an effective framework for Sonification that would be transparent to all (regardless of musical background), a better solution had to be found. Various options were considered, with simultaneous effort being applied to the design of more memorable musical patterns. It was during investigation of the role of melodic contour in pattern recognition that a potential solution was suggested.

2.1. Melodic Contour

Melodic contour has been considered by many musicologists as a means of defining relative changes in pitch [10] (with respect to time), rather than the definition of absolute values. In this manner, the shape, direction and range of a melody can all be summarised by its overall contour. Graphical contour representations were considered by composers such as Schoenberg [11] as a means of supplementing a musical score (Figure 7).

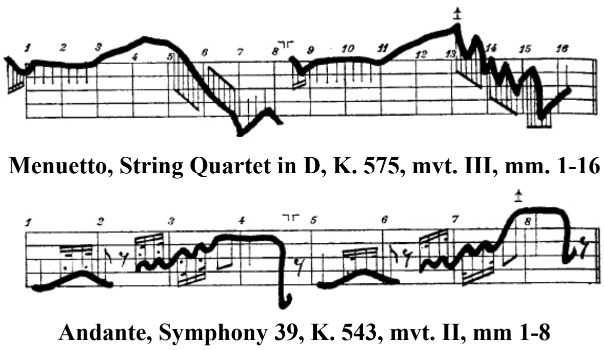

Figure 7. *Schoenberg's Contour Graphs of Selected Mozart Compositions*

Schoenberg regarded these contours as waves, a sentiment echoed by Ernst Toch [10] who regarded melodic patterns as combinations of waves and breaks of differing amplitude. This use of graphical notation to compliment (and analyse) the traditional score was taken further by the likes of ethnomusicologist Charles Adams [12], who used contour as the principle classification in his study of Native American melodies.
Adams suggested that a contour could be defined in terms of 4 minimal boundary pitches: initial pitch (I), highest pitch (H), lowest pitch (L) and final pitch (F). The relations between these 4 boundary pitches were summarised in 3 categories:

1. Slope, S- slope defines a comparison between the initial (I) and final (F) pitches as either ascending, level or descending.
2. Deviation, D- changes in direction between boundary pitches specify levels of deviation. Thus if all four pitches are equal then the deviation is zero, with subsequent disparities between any of the 4 giving different levels of deviation.
3. Reciprocal, R- The direction of the first deviation (either I to H or I to L) is referred to as its reciprocal, dictating the direction of the overall contour.

Using these features as a template, Adams defined 15 basic contour shapes for melodic classification (Figure 8). This approach performed well for defining melodies that had been reduced to groups of 4 salient pitches, and allowed Adams to define the similarities and differences between music from 2 separate Native American tribes.

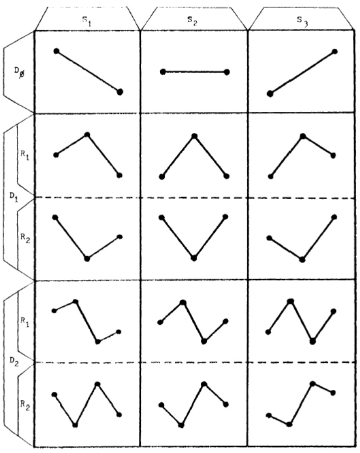

Figure 8. *Adams 15 Contour Graphs*

Contour can be considered an important part of musical memory. Dowling [13] suggests that contour information functions separately and independently from scalar information in memory. Experiments by Edworthy [14] showed that single pitch alterations in a melody could be detected by subjects as changes in contour- even when they were unable to define what pitch had been actually altered in the pattern.
This capability is believed to be present in infancy [15] (around 5 months), at a stage of development where changes in pitch cannot be recognised. It has also been shown that different brain cells are used in the processing of melodic contour [16] than are used in the detection of temporal or harmonic [17] components of music. This aspect of neural activity would again suggest that different parts of the brain are used [18] in the detection and recognition of musical events: rhythmic factors being paramount in detection, while melodic contour and range [19] and [20] being more important in the recognition of familiar and recently learned melodies.
With this in mind, it was suggested that the use of contour could be developed significantly in the pattern design framework. Although rhythmic factors (alongside pitch and timbre) were vital to the detection of an individual pattern, it could conceivably aid subsequent recognition if factors used by long-term memory were also employed.

2.2. Contour Icons

Bregman [21] suggests that visual representations of audio are of great benefit in description and analysis, with many of the Gestalt laws of grouping by proximity being equally to both visual and audio events. In view of this, a contour based design and representation method was embarked upon. In considering the possibilities of a set of icons used to represent musical patterns, it was decided that simple shapes describing melodic events would be used as the design template for those patterns.
Contour Icons were constructed using standard flowchart shapes (Figure 9), with each shape ideally dictating the final melodic shape of the pattern. These shapes were now also referred to by descriptive names intended to suggest the contour they represented, rather than by the original numerical methods.

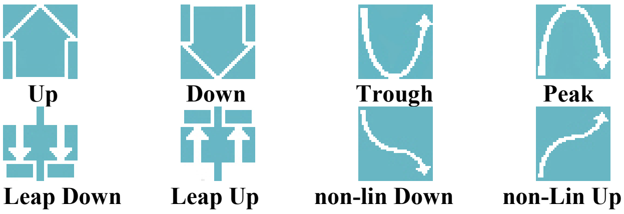

Figure 9. *Contour Icons*

The 4 boundary pitches used by Adams in his contour-based classification system were used to give definite anchors to the contour of the overall patterns being analysed. These boundary pitches allowed the shape of the melody to be accurately specified from point to point- a useful framework for contour design. This use of boundary pitches also suggested benefits when seeking to create a set of patterns as individual from each other as possible. It had been noticed during the first session tests that subjects struggled to define patterns that began or ended on the same pitch. Because of this, it was decided to use the idea of boundary pitches as part of a design template for the new Contour Icon set (Figure 10).

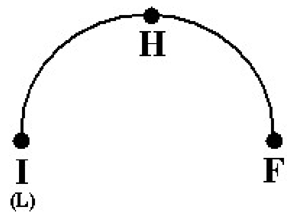

Figure 10. *Example Contour Icon defined by Boundary Pitches*

The boundary pitches would be used to ensure that each pattern differed in overall pitch from its counterparts- alongside its unique melodic contour. In this manner, it would be less likely that users would struggle to detect the beginning and end of each pattern used in a Sonification.

The new pattern set utilised simple contour shapes as suggested by the listening tests, with amendments being considered subsequent to full testing of the principle. Although the potential number of contour shapes was huge, it was decided that the 8 Contour Icons defined would form the basis of the Contour Icon set for testing purposes. The patterns were constructed to follow their associated Contour Icon as closely as possible (Figure 11).

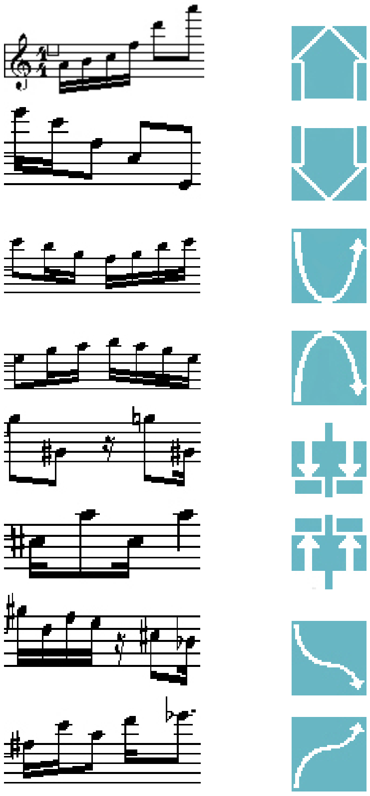

Figure 11. *Melody Contour Icon Pattern Set*

The initial (I) and final (F) pitches were specified on an individual basis (Table 1). This arrangement proved to be a very useful means of indicating the uniqueness of each pattern in a manner that had been less accurate in the initial pattern design stage.

Melody Pattern	**Initial (I)**	**Final (F)**	**Highest (H)**	**Lowest (L)**
Up	A4	A6	A6	A4
Down	E6	E4	E6	E4
Trough	C6	C6	C6	F5
Peak	E5	E5	B5	E5
Leap down	G5	G#4	G5	G#4
Leap up	C#5	A5	A5	C#5
non-l down	G#5	Bb4	G#5	Bb4
non-l up	F#5	Eb6	Eb6	F#5

Table 1. *Boundary Pitch Table for Melody Contour Icon Pattern Set*

Before testing began, the patterns themselves were tested on several test subjects (on an ad-hoc basis) to determine what level of recognition could be expected from them. Responses were virtually all completely accurate, with exceptions being noted in 2 non-Musicians who struggled with the non-linear versions of the up and down patterns. This was considered to be an acceptable margin for error in that the test schedule would never require all patterns to be used simultaneously.

The TrioSon GUI was amended to reflect the new Contour Icon patterns (Figure12), with the software data model being similarly updated to contain the new melodic patterns. Test Subjects were now required to perform a similar set of tests to those of the first test session, though this time using the Contour Icon patterns instead of the initial control set.

Figure 12. *Improved TrioSon Pattern Allocation Section*

3. CONTOUR ICON TESTING

Test subjects were asked to listen to Sonifications of basic data sets, notably lists of preferences pertaining to favourite film genre, literature, style of music and so forth. In each set of tests the available patterns were required to be matched to the available test quantities by the subject, so that on rendering they could be detected within the output pattern sequence.

In the first set of tests, subjects were given the numerically ordered control patterns, which consisted of various melodies within a major scale framework. The second set of tests provided the subjects with patterns based on (and represented by) Contour Icons. All tests were performed for a single data parameter containing between 2 and 4 variables.

3.1. Test Procedure

20 test subjects were obtained from various undergraduate and post-graduate courses taught at the Dublin Institute of Technology (DIT). Subjects participated in the test schedule on a voluntary basis, and all tests were performed over a total of 2 sessions. Testing was performed using a laptop running the TrioSon software, with stereo speakers configured for audio output via the onboard soundcard.

All tests were performed using data sets created specifically for the purposes of assessment. Each data set was organised in standard CSV format, with the variables relating to each parameter arranged in an indexed list below that parameters header (Table 2).

Index	Colour	Film Genre	Musical Style
1	Red	Comedy	Rock
2	Blue	Action	Pop
3	Green	Horror	R&B
4	Blue	Comedy	R&B

Table 2. *Example Data File Format for 3 Parameters*

Test subjects were required to use the TrioSon software to sonify a particular parameter, allocating a different musical pattern to each unique data variable in the file. The TrioSon application was configured to parse each input file by variable, and display each on a screen with the available patterns- which could thus be assigned using standard drag and drop methods. With the patterns allocated, the subject could then render the Sonification of the entire data file by either playing the file or saving it as a SMF for future reference. Tests were performed using data files containing 2, 3 and 4 variables, so that the capability to detect and recognise different numbers of patterns could be more fully assessed. It was intended to revisit the test schedule at a later data for higher numbers of patterns, but a maximum of four patterns was felt sufficient for initial purposes.

3.2. Test Questions

Subjects were asked a total of 12 questions in each test session, with the questions being grouped by variable count. Questions concerned the relative frequency of each variable in the file, with 2 marks being awarded for each correct response (or 1 for a response within +/- 1 of the correct value). Test subjects were allowed to listen to each Sonification up to 3 times as required. At the end of each test session a set of Task Load Index (TLX [22]) tests were performed with each subject, to better assess their perceptions of the Contour Icons in testing. These results were intended to highlight any areas of improvement that had been achieved as a result of using Contour Icons.

4. RESULTS

The results of both test sessions were collated by variable count (Figure 13), and also by session (Figure 14).

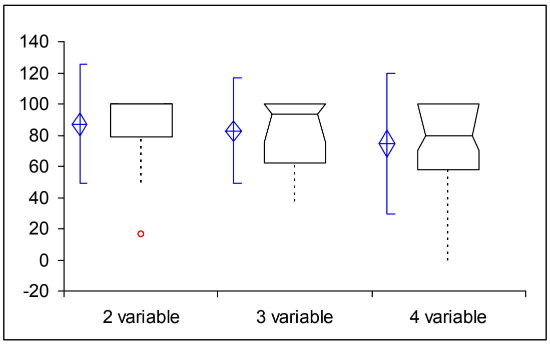

Figure 13. *Box Plot Representation of Test Results by Variable Count*

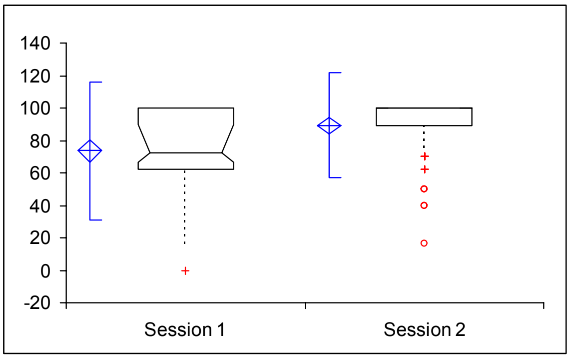

Figure 14. *Box Plot Representation of Test Results by Session*

4.1. Overall Results

The overall average score in both sessions was compared, with an increase from 73.53% to 89.4% for the Contour Icon tests being observed. Scores by variable count were also considered, with an expected reduction being observed from 87.01% (2 variable) through 82.81% (3 variable) down to 74.5% for the 4 variable condition. To confirm the significance of these results, a 2-way Anova [23] was performed between variables and sessions. The results of the Anova showed a significant improvement between sessions due to the use of Contour Icons ($F(1,120)= 14.88$, $p= 0.0002$)). It was also noted that performance diminished with higher variable counts, and the Anova again confirmed this with $F(2,120)= 3.22$, $p= 0.0434$). These results were encouraging, as they suggested that the introduction of Contour Icons had improved the recognition rates of subjects during tests.

4.2. TLX Test Results

As previously mentioned, all test subjects were asked to fill out TLX test questionnaires to determine how they had evaluated the introduction of Contour Icons (Figure 15).

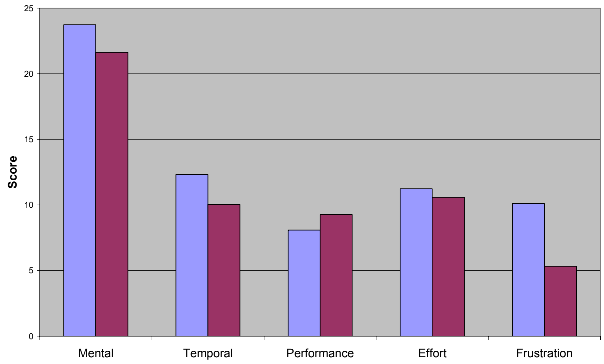

Figure 15. *Post-test TLX results by Session*

Results for the first session had been fairly high, particularly for the mental demand that subjects felt they had been placed under. Although the overall workload scores had displayed a significant reduction from 66.33% (session 1) to 58.05% (session 2) with $T(20)= 2.20$, $p= 0.0336$, the reduction in individual workload statistics had not been so pronounced. Interestingly, the only individual score that displayed significant reduction was that of frustration, which had dropped from 10.12% (session 1) to 5.33 (session 2) with $T(20)= 2.40$, $p= 0.0215$. This was again encouraging, as it confirmed testing observations which suggested that most users were far more comfortable with the Contour Icon patterns than with the control set.

5. CONCLUSIONS

Overall, the introduction of Contour Icons made a significant improvement to the pattern recognition performance of the test subjects. It was noted that there was a significant reduction in recognition rates between 2 and 4 variable conditions, but it was felt that a score of 74% was still sufficiently high enough to warrant further investigation. This improvement in performance due to Contour Icons was matched by feedback obtained during testing, which suggested that all users preferred the Contour Icons to the control set. Indeed, several test subjects with musical training felt that using Contour Icons was 'cheating', and this again confirms the greater degree of comfort and affinity that Contour Icons provided to all those tested.

Although there was a significant reduction in workload statistics, the amount of mental and temporal demand that test subjects felt they were under was still considered too high. Further work conducted as part of this research into the role of Rhythmic Parsing in Sonification aims to reduce these demands, while simultaneously improving results even further.

Contour Icons were introduced as part of a more extensive framework for the Sonification of data sets, and to this end they provided an improved solution for pattern recognition. Nevertheless, the icons detailed here are by no means comprehensive, and should rather be considered as a first stage in an ongoing process of development. By introducing basic patterns that simultaneously mimic both shapes and gestures (in a manner similar to that of an orchestral conductor), it is intended to stimulate a more comprehensive means of recognition than that performed by a single sense in isolation. The potential for information delivery using the combination of differing senses is obvious [24], and it is hoped that the principles suggested by Contour Icons may cover some ground towards its realisation.

6. FUTURE WORK

Further research is currently ongoing in conjunction with a mobile network service provider, to consider the possibilities of developing Sonification on mobile devices. It is intended to investigate the potential of Contour Icons on such devices, with a view to producing a more robust and verbose mobile communication framework than the one currently in operation. Testing is currently being performed on new Contour Icon patterns to ascertain those most recognisable to the listener. It is intended to investigate the potential of Contour Icons in higher variable conditions than those tested here, to determine whether a headroom of recognition exists for basic musical shapes.

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