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The Singing Plant: Analysis of plant-wide disturbances through sonification

First Report

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October 2002

Abstract

Sonification is the process of representing data by means of audio signals. In this work the aim was to provide an insight into how sonification could be utilised to diagnose plant-wide disturbances, which are detrimental to efficiency and economy in chemical plants.

Supporting evidence from existing research on the use of sonification in numerical analysis has been provided in addition to a review of the key considerations that would be involved in further investigation of this technique. A review of experimentation on direct sonification techniques using Matlab revealed that the audition of a frequency modulation sample error signal was effective at conveying information about the behaviour of the signal. Amplitude modulation of the sample signal was found to be less effective, and phase modulation of the sample data did not provide a meaningful insight into signal behaviour.

A comprehensive plan of the work to be carried out is presented in addition to a project budget and an assessment of the risk inherent in further work.

Keywords: sonification, plant-wide disturbance, chemical plant, auditory display, Matlab, frequency modulation

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1. INTRODUCTION

Sonification, by analogy with *visualisation*, is the process of making data audible (Madhyastha and Reed 1994).

1.1. Aim

This document is a proposal for research on the sonification of process data in order to aid control engineers and operators in the assessment of the behaviour of a chemical plant with respect to the disturbances that may be present.

The aim of the project is to investigate the conversion of chemical process data to audio data in order to utilise the excellent sensory perception provided by the human ear in the most intuitive manner.

1.2. Motivation

Plant-wide disturbances have a detrimental effect on the product quality and running costs of plants (Thornhill *et al.* 2001). This has led to extensive research in this area including analysis using conditional entropy (Dobson and Thornhill 2002) as well as using data-driven techniques and process understanding (Thornhill *et al.* 2002a). This project will utilise sonification as another method of data-driven analysis of plant-wide problems.

Due to the large volume of process measurements within a plant it is difficult to diagnose and analyse plant-wide disturbances by visually tracking several processes simultaneously. The limitations of visual information analysis are that visual indicators require active examination and cognition, and furthermore, in order to identify a visual indicator it must lie within the field of view (Noirhomme-Fraiture *et al.*, 2002). These data handling limitations can be overcome by sonification because human audio perception is not limited by direction and is capable of *parallel listening*, the ability to keep track of several different processes simultaneously, as defined by Kramer (1994).

Sonification is not a new concept as sound is used in many familiar applications such as the Geiger counter, ultrasound scanning of living tissue and sonar. However, sonification research, its international recognition and the development of sonification standards have only become established over the last decade (Sullivan 1998). According to Kramer *et al.* (1999) the technical definition of sonification is:

> *"The use of non-speech audio to convey information. More specifically, sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation."*

The main organisation that focuses on the development of sonification is the International Community for Auditory Display (ICAD), established in 1992. ICAD is a forum for presenting research on the use of sound to display data, for monitoring systems, and to provide enhanced user interfaces for computers and virtual reality systems. Kramer *et al.* (1999) of the ICAD have prepared an excellent review on the field of sonification and related research developments. An interesting example of successful sonification was its use in confirming that the Voyager 2 spacecraft was moving through a micrometeoroid field because electromagnetic disturbances due to the micrometeoroids could be heard although they could not be seen (Kramer *et al.* 1999).

The use of sonification to overcome the limits of visual data processing has been applied in the field of numerical fluid flow simulation (Childs 2001). In this case sonification provided the ability to monitor the progress of convergence of the data throughout the flow field, as opposed to the one or two locations that were practical in visual monitoring of the solution, and enabled the user to hear whether the solution was evolving as expected, on a global basis. Kramer (1994) defines this ability to perceive an organised whole that is more than the sum of its parts as *auditory gestalt formation*. It may be possible to use this sense of perception to detect plant-wide disturbances based on a plant schematic such as that shown in figure 1.2, in which the process measurements affected by a plant-wide oscillatory disturbance are represented by circular symbols.

Interestingly Childs (2001) also concluded that the addition of sound also allowed the engineer to hear roughly where in the domain a problem might exist. Kramer (1994) defines this ability to perceive an individual audio pattern as *orienting* and it may be possible that this sense of perception would enable a plant engineer to hear the root cause of a plant-wide disturbance.

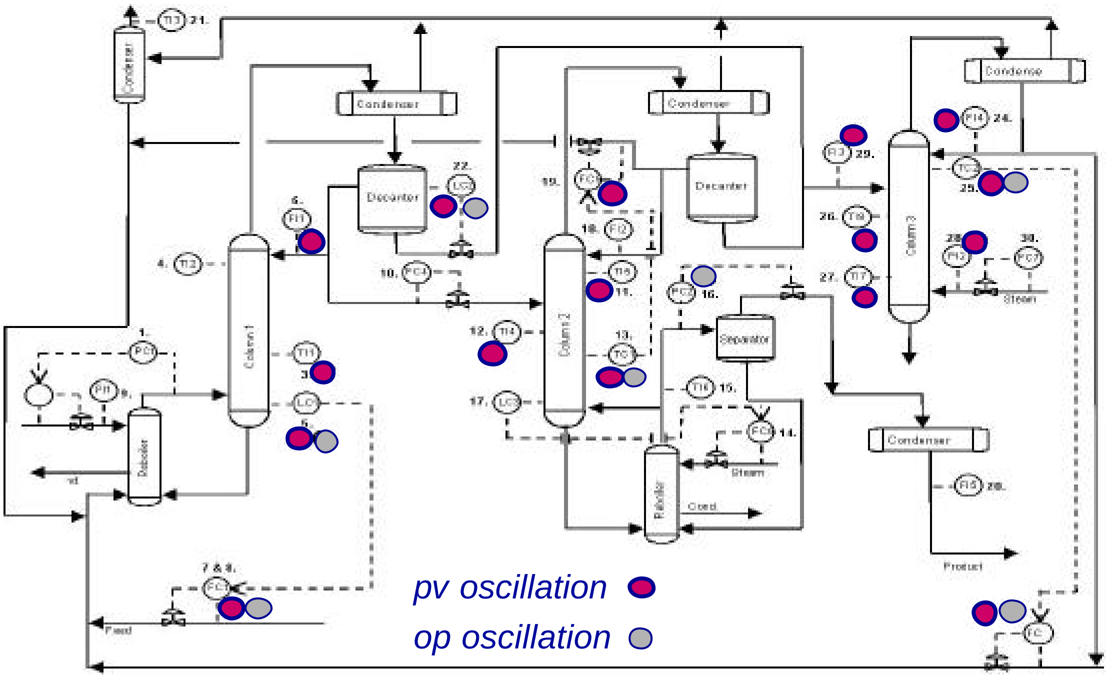

Figure 1.2. Process schematic showing a plant-wide oscillatory disturbance. The circular symbols show the process measurements affected by a plant-wide oscillation. From Thornhill *et al.* 2002a.

The ultimate goal in carrying out this work is to provide an auditory interface in which disparities in plant behaviour from optimum levels could be determined by listening to different parts of the plant, as well as listening to the plant as a whole. Thus each component within the plant could be likened to an individual musical instrument within the orchestra that is the complete plant.

An additional goal is to demonstrate the benefits that sonification of plant data would provide. Based on a mock-up of a schematic such as that shown in figure 1.2, one could perhaps click on an individual tag and listen to the audio representation of the process measurements at that point, or alternatively one could select an area of the plant and hear some common feature from all the tags in the selected area.

1.3. Layout of report

The focus of this report is biased towards project planning and management hence the background to sonification work (Section 2) has been kept to a minimum but nevertheless covers essential ground for understanding the preliminary review of direct sonfication techniques (Section 3).

In order to correctly assess the risk inherent in carrying out this project a detailed specification of the work that is to be carried is defined in Section 4.1. An analysis of the distribution of work, time management and the critical path towards project completion can be found in Section 4.2. A draft assessment of the generic risk associated with this project has been conducted by the students involved in this project and has been submitted to the academic supervisor for approval (Appendix A).

Section 5 provides the conclusion of the work in this report and presents an analysis of the future work involved in this project. This document has been written in accordance with the guidelines suggested by Selviah (2000).

1.4. Statement of deliverables

The students working on this project have agreed to work towards the deliverables listed in table 1.4 and have indicated the priority and risk they believe is associated with each deliverable.

TITLE	PRIORITY	RISK OF FAILURE	ASSOCIATED DATES
Research	High	Medium	10/02 – 12/02
1 - Provide a review of direct sonification techniques. 2 - Provide a review of centres of expertise in the use of sonification for data analysis. 3 - Provide a review of the efficacy of a range of sonification methods. 4 - Provide a justification for choosing 3/4 promising methods to be investigated further. 5 - Provide a review of the efficacy of sonification in enabling the user to make enhanced judgements about plant behaviour. 6 - Provide a review of whether sonification can be used to detect the root cause of a plant-wide disturbance.			
Programme development	High	High	11/02 – 01/03
7 - An audio initialisation test to ensure that sound signals are in the audible range. 8 – Plant data prepared in a format suitable for sonification. 9 - A programme to manipulate sonified tag data. 10 - Evaluation of the entire sonification process using a sample of data. 11 - All plant data sonified based on the 3/4 methods chosen. 12 - A programme capable of simultaneous replay of multiple sonified tag data in order to represent the plant. 13 - Design simulated plant based on schematic. 14 - Develop audio demonstration of sonification concept applied to plant schematic.			
15 - Project proposal	Medium	Low	17/01/03
16 - Progress report	Medium	Low	17/01/03
17 - Final report	High	Low	To be decided
18 - Oral presentation	High	Low	To be decided

Table 1.4. List of project deliverables including priority, risk of failure and associated date(s).

1.5. Scope

It is not anticipated by any party involved in this project that a fully functional real-time sonification processing engine can be developed for chemical plants, although it is a primary directive of this project to demonstrate the benefits that such a set-up would provide. Hence the work in this project will not involve processing real-time plant data.

On the other hand, in the context of developing an auditory interface it will be advantageous to enable the user to hear sounds based on their interaction with a user interface (Tannen 1998). Therefore a real-time sound manipulation engine should either be developed or facilitated.

The publication of the work carried out in this project in a journal or conference is not in fact a deliverable of the project. The parties involved in the project will review the suitability of this low priority and high-risk task should the opportunity arise.

2. BACKGROUND

2.1. Auditory perception

Basic definitions

Based on the work of Kramer (1994) the benefits of auditory perception in the context of monitoring plant wide disturbances have been defined and are listed in table 2.1.

ASPECT	ADVANTAGE
Aural cognition	In situations where operators cannot see directly where a problem is occurring within the plant cycle (due to limitations of visual resolution and perception) sonification might enable the operator to hear where problems lie.
Responsiveness	It has been shown that the response time to acoustic signals can be shorter than to visual signals.
Alarm	Audio signals can be heard omni-directionally and therefore are more effective in the capacity of alerting the control engineer.
Background audio processing	Audio information that is repetitive or expected has low informational value and the human ear accordingly gives a lower priority to this information. Any significant change will have a noticeable effect on one's attention.
Auditory resolution	In a visual display one cannot tell the difference between a light flashing at 40 or 10,000 times a second. Hearing on the other hand allows us to distinguish between frequencies of 20-20,000 Hertz with a resolution that can detect a 1% difference in frequency within this range.

Table 2.1. Benefits of an auditory interface in the analysis of plant data based on Kramer (1994).

Interplay of audio and visual information

Noirhomme-Fraiture *et al.* (2002) have conducted experiments on the suitability of sound as a medium for the purpose of data representation and an important conclusion of their work is that while data audition is an effective communications channel and complements data visualisation well, it could not be a substitute for data visualisation.

Noirhomme-Fraiture *et al.* (2002) also draw attention to the fact that visual and audio *data mining* should be synchronised in order to be most effective. Figure 2.1 shows their representation of the way in which in visual and audio data mining are interrelated.

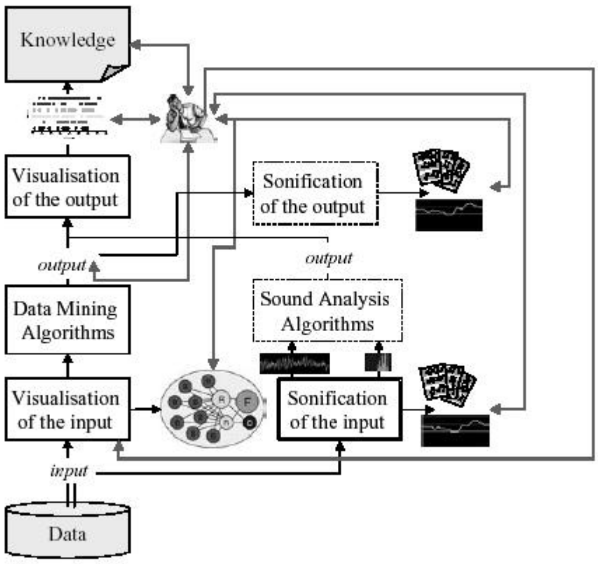

Figure 2.1. Interrelationship of human audio-visual data mining, from Noirhomme-Fraiture *et al.* (2002).

2.2. Properties of sound

<u>Pitch</u>

Pitch is related to the frequency of sound waves. The human brain interprets logarithmic changes in the frequency of a sound waveform as linear changes in pitch, and despite this fact variation of pitch is a very intuitive way to express relative magnitude. The human ear is most sensitive to frequencies in the range 20 – 4,000 Hertz and this scale corresponds approximately with the range of notes on a piano keyboard (Madhyastha and Reed 1995).

The disadvantage of pitch mapping is that in order for a sound to be heard it must last a certain number of cycles, with lower frequency notes having to be heard for longer durations than higher frequency notes in order to be perceived.

<u>Loudness</u>

Although *loudness* is linearly related to the amplitude of a sound wave, the cognition of loudness is influenced by several other characteristics of sound including pitch and timbre. Furthermore the perception of the loudness of a sound is influenced by the loudness of previous sounds and it is for these reasons that loudness does not really have a linear scale. Loudness could be used to convey information regarding a small number of discrete values (Madhyastha and Reed 1995).

<u>Timbre</u>

The waveform of a sound i.e. the sum of all of the constituent sound waves, is the *Timbre*. It is the timbre that distinguishes notes of the sample pitch and amplitude played from different instruments because the harmonics that constitute those notes are dependant on the acoustics of that instrument (Wilkie 1993).

Location

Location refers to the perception of the origin of a sound and depends on the physical location of the source as well as on the environmental acoustics and the shape of the ear. One-dimensional mapping of sound can be readily achieved because most sound systems support *stereo*, the origination of sound from two separate sources. Although stereo sound is a limited technique of sound spatialisation, it could be used to enhance perception of visualised data (Madhyastha and Reed 1995).

Rhythm

Music is usually organised around a *rhythm* or beat which is indicative of the periodicity of the notes from which it is composed (Madhyastha and Reed 1995). One of the most important duties of a *Disc Jockey* (DJ) is to match the rhythm between two different pieces of music in order to achieve *consonance*, a harmonious rhythm (Jarrel 2001). Conversely *dissonance* is when two different pieces of music sound inharmonious and perhaps this property could be used to allow plant operators to hear plant-wide disturbances by listening to optimum and actual sonification data from the plant.

Duration

One cannot accurately discriminate between the *duration* of different sounds unless they differ substantially hence duration cannot be used to present quantitative data. Duration is useful in representing activity lifetimes and highlighting overlapping activities (Madhyastha and Reed 1995).

2.3. Software requirements for sonification

Microsoft Excel

The supervisor has informed the students that the plant data will be provided as Excel files. This raw data has to be processed so that it can be used for signal processing.

Matlab

It is expected that the development work in this project will involve rigorous numerical analysis, filter design and access to an audio interface. To date, Matlab has been used as the development environment for conducting this work because it satisfies the aforementioned requirements and is readily available within educational and engineering institutions. However, Matlab is limited in its use for developing a graphical user interface and the functionality of the audio interface is limited. In any case Matlab will probably be used in an intermediate step for signal processing purposes.

Musical reproduction

If a sonification system were to be implemented in an industrial environment then the sheer volume of data would necessitate an analysis of effective methods of storing musical information. Two promising schemes for storing musical information in a non-space-intensive manner is the use of Musical Instrument Digital Interface (MIDI) synthesisers or the storage of audio information compressed using the Motion Picture Experts Group Audio Layer 3 (MP3) algorithm.

The MIDI protocol is based on the use of instruction mapping to a digitally synthesised instrument regarding the musical notes that should be played (Byrd and Crawford 2002). Hence the data that needs to be stored is an instruction set of the notes that should be played along with their duration, pitch and amplitude, as opposed to storing the actual sounds. By analogy to tangible musical instruments one could liken instructions to a MIDI instrument to the punch cards based upon which primitive self-operating pianos played music.

The problem that the use of MIDI synthesised sound storage has is that the user of such a system must have a MIDI synthesiser software programme installed. If the actual sound were recorded into a sound file such as the MP3 format then the file size would be considerably larger but nevertheless the file would be more portable as generic applications exist that have the capability of playing these sound files. By analogy to programming languages we could say that a MIDI program is a script that is parsed every time a program is executed whereas an MP3 file is an optimised and pre-compiled programme file.

Java

It was originally not anticipated that a single software programme could satisfy all of the requirements for the development work in this project. In particular the students were of the opinion that it may be more advantageous to use 3rd party software programmes specifically designed for music editing e.g. Syntrillium Cool Edit 2000.

However, it has recently been discovered by the students that the Java 2 programming language includes an Application Programming Interface (API) capable of audio capture, manipulation and play back in addition to MIDI synthesis and sequencing (Sun Microsystems 2002). In fact Childs (2001) also used a sound manipulation engine developed using the Java programming language although the he specifically was using a 3rd party software development kit called JSyn.

In addition to the availability of extensive sound manipulation capabilities in Java the advantage of its facilitation is that it has excellent functionality in designing graphical user interfaces, especially when used in the guise of Applet programs as these can be used through most Internet browsers. As a fully functional development environment it may be possible to use Java even for the signal processing work that was originally going to be undertaken in Matlab.

Microsoft PowerPoint

For the purpose of demonstrating the goal of the work in this project and possible future work, Microsoft PowerPoint (an established presentation design software package) will be used. It is expected that the audio replay or demonstration of a graphical user interface will not be fully comprehensive, but sufficient to show the plausibility of the concept.

2.4. Considerations of plant behaviour

Thornhill (2002b) notes that the majority of plant signals are of very low frequency. As outlined earlier the human hearing range of frequencies is between 20 – 20,000 Hertz and in particular the human ear is most sensitive to frequencies in the range 20 – 4,000 Hertz. The process measurements obtained from plants and more importantly plant-wide disturbances may have a frequency outside the audible range and so some signal processing work is required in order make the data audible. In fact the audible range is user specific and so sonification schemes will have to be flexible enough to be optimised to the user's range of sound perception. Hence it could well be advantageous for robustness of design to incorporate an audio initialisation test.

Another important consideration that is described by Thornhill (2002b) is that process measurements outnumber the different modes of behaviour exhibited. Hence there are signals that will provide similar information and it may prove advantageous to filter out some of this redundant information in order to draw the attention of the user to a common disturbance that the processes may share.

3. DIRECT SONIFICATION TECHNIQUES

3.1. Experiment

A series of brief experiments were carried out by the students working on the project based on a sample Matlab program provided to them by the supervisor. A copy of the Matlab scripts used can be found in Appendix B. The purpose of these experiments was to investigate the efficacy of direct sonification of data through the use of amplitude, phase and frequency modulation as an indicator of the behaviour of a process measurement obtained from the plant. Furthermore, the experiments were also intended to be an analysis of the sound capabilities of Matlab and to demonstrate the interrelation between visualisation and audition of the data.

The experiments were based on a sample error signal, which was calculated from set point and process variable data (provided by the supervisor) and then scaled. In order to enhance the audition of the data the error signal (1,000 data samples) was interpolated to 200 times its original sequence length. The interpolated signal was then sampled at 22,000 Hertz and modulated on a 440 Hertz carrier signal (which corresponds to Middle C on the piano keyboard) and the modulated signal was played directly through the default sound device of the operating system at a sampling rate of 22,000 Hertz which resulted in just over 9 seconds of audio data.

3.2. Results

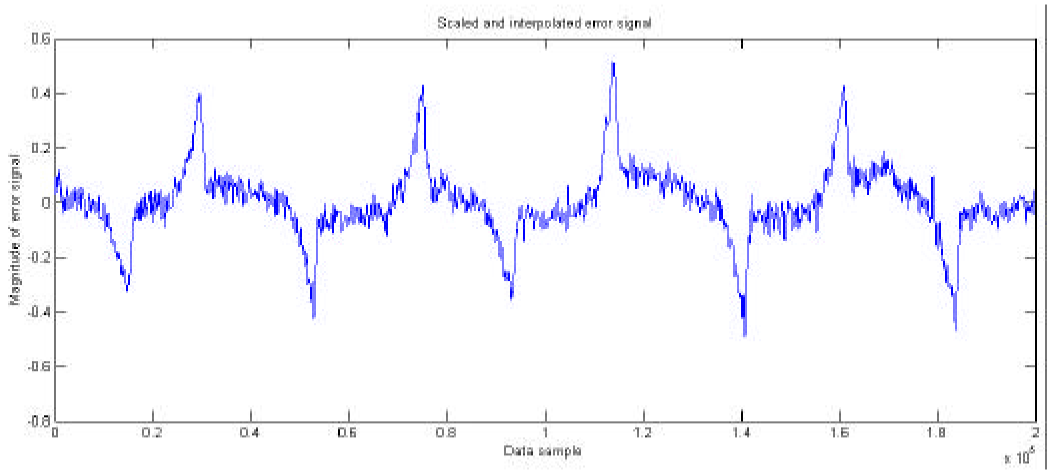

Figure 3.2.1. Scaled and interpolated error signal from sample plant data

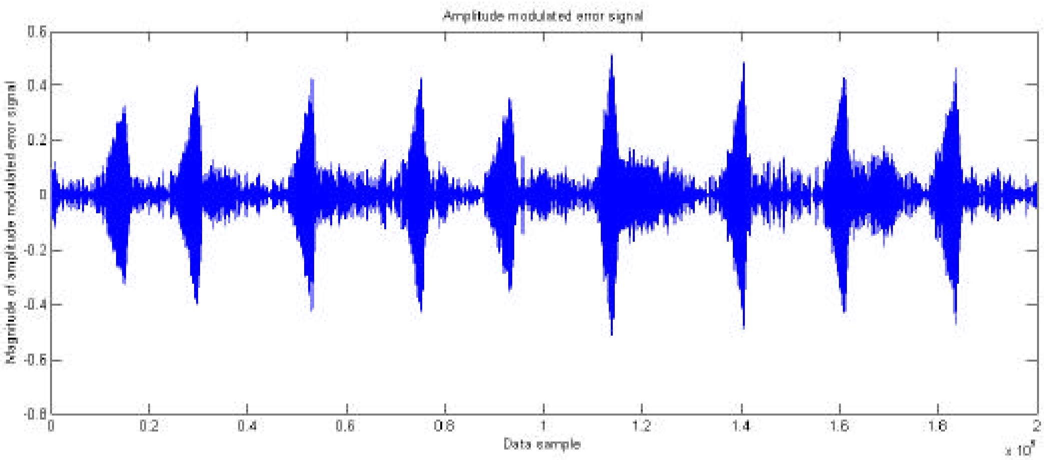

Figure 3.2.2. Amplitude modulated error signal from sample plant data

Figure 3.2.1 shows the magnitude of the interpolated error signal (200,000 data samples). Figure 3.2.2 shows the waveform of the amplitude-modulated error signal. It was decided to not include the frequency-modulated and phase-modulated waveforms as the variation in frequency and phase cannot be seen easily. By the nature of the experiment the actual results from the signal audition cannot be included in a written report.

3.3. Discussion

The audio signals produced by the different modulation schemes did not convey a satisfactory representation of the data when heard on their own, which is in keeping with the work carried out by Noirhomme-Fraiture *et al.* (2002) – see section 2.1. However replay of the audio signal while looking at the visualisation of the error signal enabled one to draw meaningful conclusions on the efficacy of the modulation method in communicating the behaviour of the error signal. Although it seems trivial, it must be stated that there is a clear disparity between the level of organisation of the information in the visual domain and in the audio domain. If in the visual domain the plot of the signal did not contain a clearly defined plot area, title, axis labels and axis indicators, then it would probably also not convey a satisfactory representation of the data when seen on its own. To this effect it is clear that work has to be carried out on developing a standard for audio equivalents of a title, axis labels and axis indicators (the students have not yet come across any existing standards). A basic method of conveying information about the x-axis scale is to include a second audio track with a regular pattern of beats as this would provide the user with an insight into the progress of the signal sonification, similar in principle to the metronome used by musicians.

Frequency modulation was certainly the most promising modulation scheme and clearly indicated whether the signal was increasing or decreasing and the behaviour of the audio signal matched that seen visually exactly, reaffirming the importance audio-visual synchronicity noted by Noirhomme-Fraiture *et al.* (2002) – see section 2.1. This method of modulation certainly has the promise of being a clear indicator of magnitude. Perhaps one method of standardisation would be to categorise the signal magnitude into discrete values such as the notes reproduced by a piano that could then be meaningfully recognised by the trained ear.

Based on an analysis of figure 3.2.1, which shows the error signal magnitude for the 200,000 data samples, and figure 3.2.2, which shows the amplitude modulated error signal, one can instantly see that the amplitude modulation has meant that only the magnitude of the signal is represented by the audio data. This problem could be overcome by translating the magnitude of the error signal such that there are no negative values. Except this flaw in the test of the correlation of the audio and visual data, it was discernable that the error signal was increasing or decreasing in value, although this variation was certainly less clearly identifiable than the frequency modulated signal, from which one could remember the sound of the highest and lowest point of the error signal. The phase-modulated signal did not convey any meaningful information about the behaviour of the error signal.

4. PLANNING

4.1. Technical specification

4.1.1. Work packages

The details of the work packages that have been agreed upon by the students and the supervisor are listed in table 4.1.1 below.

1	**TITLE**	Direct sonification experiment
	REQUIRED RESOURCES	Personal computer, Matlab, Both Students
	AIM	Experiments into the efficacy of information conveyed by sonifying sample data using direct modulation techniques: FM, AM and PM
	RELATIONSHIP OTHER WORK PACKAGES	Matlab is to be used for initial direct sonification experiments and may be used for signal processing purposes
	TIME BUDGET	3.5 days
	PROPOSED DATES	14/10/02 - 17/10/02
2	**TITLE**	Conduct Web of Science journal and proceedings search, and Internet search on sonification, audification, auditory interfaces, sound manipulation, audio algorithms and acoustic monitoring
	REQUIRED RESOURCES	Personal computer, Athens access, Internet access, Both Students
	AIM	Identify established research areas in sonification and attempt to find similar work
	RELATIONSHIP OTHER WORK PACKAGES	It is important to have an overview of the range of sonification techniques available in order to choose 3 / 4 promising method to investigate further
	TIME BUDGET	3 days
	PROPOSED DATES	07/10/02 - 09/10/02
3	**TITLE**	Write project proposal
	REQUIRED RESOURCES	Personal computer, Microsoft Word, Internet access, Both Students
	AIM	Provide supporting evidence on the plausibility of the application of sonification to process data in addition to planning of future work.
	RELATIONSHIP OTHER WORK PACKAGES	A clear plan of work has to be established and the risks inherent in the project have to be recognised prior to beginning work.
	TIME BUDGET	11 days
	PROPOSED DATES	11/10/02 - 25/10/02
4	**TITLE**	Choose 3 / 4 promising methods of sonification to investigate further
	REQUIRED RESOURCES	Personal computer, Microsoft Word, Internet access, Matlab, Both Students
	AIM	Test a range of different sonification methods based on sample data in order to assess the potential of different methods.
	RELATIONSHIP OTHER WORK PACKAGES	It is important to justify the reasons why the work is progressing in a particular manner and performing a test-case analysis will allow the students to make more insightful decisions.
	TIME BUDGET	7 days
	PROPOSED DATES	04/11/02 - 12/11/02
5	**TITLE**	Manipulate audio signals between bounds of audible perception in terms of pitch, amplitude, stereo balance and design a user interface for the program

	REQUIRED RESOURCES	Personal computer, Matlab, Seyed Ali Mirkhani
	AIM	To design and create a hearing test so that sonification can be customised to each individual user and so the signals produced are audible to each person.
	RELATIONSHIP OTHER WORK PACKAGES	In sonification work it is fundamental that users can easily hear the signals being produced.
	TIME BUDGET	4 days
	PROPOSED DATES	29/10/02 - 01/11/02
5	TITLE	Look up list of Books and Journals recommended by ICAD
	REQUIRED RESOURCES	Internet access, Hoe Cheng
	AIM	ICAD is the international research centre for sonification and hence investigation of publications and journals recommended by them will seek to ensure that major research work will not be overlooked.
	RELATIONSHIP OTHER WORK PACKAGES	This research work may open up previously undiscovered avenues of work that could be followed.
	TIME BUDGET	5 days
	PROPOSED DATES	15/11/02 - 21/11/02
6	TITLE	Prepare plant data in a format suitable for sonification
	REQUIRED RESOURCES	Personal computer, Microsoft Excel, Seyed Ali Mirkhani
	AIM	The supervisor has advised the students that the data from the chemical plant are normally in Microsoft Excel format and the data will probably have to be put into a simpler format for use in Matlab and perhaps Java.
	RELATIONSHIP OTHER WORK PACKAGES	This work is required so that experimentation on sonification of real data can begin.
	TIME BUDGET	1 day
	PROPOSED DATES	Depends on when data is provided to students.
7	TITLE	Develop a program to manipulate sonified tag data
	REQUIRED RESOURCES	Personal computer, Internet access, Java, Java Sound API, Matlab, Both Students
	AIM	Review the suitability of each method of audio storage. The options currently in discussion are MIDI or MP3.
	RELATIONSHIP OTHER WORK PACKAGES	This preliminary work is vital to the development of the sonification algorithms that will be the core of the implementation from tag data to audio sounds.
	TIME BUDGET	1 day
	PROPOSED DATES	29/10/02 – 16/12/02
8	TITLE	Test entire sonification process using a sample of data
	REQUIRED RESOURCES	Personal computer, Internet access, Java, Java Sound API, Matlab, Both Students
	AIM	Review the efficacy of each method of sonification that has been developed.
	RELATIONSHIP OTHER WORK PACKAGES	It is important to ensure that the work can be carried out on the entire data set, and to identify possible problems.
	TIME BUDGET	8.5 day
	PROPOSED DATES	23/12/02 – 02/01/03
9	TITLE	Sonify all plant data based on the 3 / 4 methods chosen
	REQUIRED RESOURCES	Personal computer, Internet access, Java, Java Sound API, Matlab, Both Students

	AIM	The aim of the program is ultimately to listen to more than one process measurement hence it is imperative that all of the data is sonified.
	RELATIONSHIP OTHER WORK PACKAGES	The sonified data from multiple tags will be required in order to carry out the work in the next work package.
	TIME BUDGET	24 day
	PROPOSED DATES	02/01/03 – 05/02/03
10	**TITLE**	Design a program capable of simultaneous replay of multiple sonified tag data
	REQUIRED RESOURCES	Personal computer, Internet access, Java, Java Sound API, Matlab, Both Students
	AIM	The aim of the synthesis work in the project is to investigate if the audio domain can really overcome the overload that is experienced when large volumes of data are analysed visually.
	RELATIONSHIP OTHER WORK PACKAGES	This is important in being able to demonstrate the concept that plant-wide disturbances can be detected through sonification.
	TIME BUDGET	21 day
	PROPOSED DATES	05/02/03 – 06/03/03
11	**TITLE**	Write a progress report
	REQUIRED RESOURCES	Personal computer, Microsoft Word, Internet access, Both students and supervisor
	AIM	Review the work undertaken to date and plan the course of the future work to be carried out.
	RELATIONSHIP OTHER WORK PACKAGES	It is important to compare the progress of the report in order to adjust the aims of the work if required or to realise if there are any major hindrances in further work being carried out.
	TIME BUDGET	35 days
	PROPOSED DATES	25/11/02 – 10/01/03
12	**TITLE**	Design simulated plant based on schematic
	REQUIRED RESOURCES	Personal computer, Microsoft PowerPoint, Java, Java Sound API, Matlab, Both Students
	AIM	To experiment with the concept of having a synchronous audio-visual interface based on a plant schematic for diagnosis of plant disturbances through sonification.
	RELATIONSHIP OTHER WORK PACKAGES	This is the ultimate aim of the project in terms of development work.
	TIME BUDGET	7 day
	PROPOSED DATES	06/03/03 – 17/03/03
13	**TITLE**	Write final report
	REQUIRED RESOURCES	Personal computer, Microsoft Word, Internet access, Java, Java Sound API, Matlab, Both Students and Supervisor
	AIM	To review all of the work undertaken in the project and provide a retrospective analysis of the work compared to the objectives stated in this report.
	RELATIONSHIP OTHER WORK PACKAGES	This document should encapsulate all of the achievements and pitfalls that we have come across in our work, drawing out the main conclusions and suggesting possibilities for future work.
	TIME BUDGET	38 day
	PROPOSED DATES	29/01/03 – 21/03/03
14	**TITLE**	Develop an audio demonstration of sonification concept applied to plant schematic
	REQUIRED RESOURCES	Personal computer, Microsoft PowerPoint, Internet access, Sound files, Both Students
	AIM	Provide a readily available method of demonstrating the concept on which this work is based.

	RELATIONSHIP OTHER WORK PACKAGES	It is important to be able to demonstrate the end-result, or perceived end-result or our work.
	TIME BUDGET	4 day
	PROPOSED DATES	21/02/03 – 26/02/03
15	TITLE	Prepare oral presentation
	REQUIRED RESOURCES	Personal computer, Microsoft PowerPoint, Internet access, Java, Java Sound API, Matlab, Both Students and Supervisor
	AIM	To present on the work carried out in the report.
	RELATIONSHIP OTHER WORK PACKAGES	This completes the work done in the project and presents the concepts that were involved and the work undertaken.
	TIME BUDGET	17 day
	PROPOSED DATES	06/03/03 – 28/03/03

Table 4.1.1. Details of work packages agreed upon by students and supervisor.

4.1.2. Project risk assessment

This section addresses the technical risk involved in this project. Table 4.1.2 lists the uncertain parts of the work, a discussion of methods to prevent the risk from occurring in addition to a contingency plan.

RISK	METHOD OF PREVENTION	CONTINGENCY PLAN
Suitable chemical plant data cannot be obtained.	Approach several chemical plants for suitable data.	1 - Work on data used by supervisor in previous chemical plan projects. 2 - Seek alternative data from other academics. 3 - Generate test case data.
Matlab cannot cater to signal processing of data.	Test capability of Matlab using sample of data prior to manipulation using complete data set.	1 - Use the Java programming language
Cannot obtain suitable bridge between processed Matlab data and sound replay from a MIDI synthesiser or MP3 player.	Investigate existing research work on audio processing in Matlab.	1 - Use Java for all development work. 2 - Dump data into suitable intermediary format and manually import into audio replay program.
Illness	Unpreventable.	1 - Reduce investigation of 4 promising sonification methods to 3 methods only. 2 - Allocate slack time during Academic holidays.
Hardware failure	Keep all work backed up on UCL and departmental network drives. Backup all work once a week	1 - Restore last known working copy of programmes and data.

Not being able to design successful mock-up	Plan presentation well in advance. Seek help from PowerPoint professionals on how to implement mock-up.	1 - Play sounds through an alternative device e.g. from an audiocassette, and have poster made of plant schematic. 2 - Obtain program that records user's action in Windows and play sound from an alternative software program. 3 - Record a movie of the sounds playing when mouse is clicked and replay movie.

Table 4.1.2. Assessment of project risk, method of prevention and contingency plan.

4.2. Project management

4.2.1. Work distribution

The students working on this project have agreed to share the balance of work equally, although due to Seyed Ali Mirkhani having fewer lectures in the first term his workload is slightly higher during that term and slightly lower in the following term.

4.2.2. Project schedule

The milestones in this project and their associated dates are listed in table 4.2.2 along with numbered references to the associated deliverables listed in table 1.4.

MILESTONE	ASSOCIATED DATES
Collect literature search information and prepare for preliminary review [2]	11/10/02
Prepare data for project proposal [15]	17/10/02
Submit project proposal [15]	11/10/02
Audio initialisation test [7]	04/11/02
Obtain plant data from supervisor [8]	15/11/02
Collate literature search information and prepare for review [2]	21/11/02
MIDI synthesis program [9]	20/12/02
Submit progress report [16]	17/01/03
Completion of programming work [9-13]	20/03/03
Submit final report [3-6,17]	28/03/03
Audio demonstration of concept in PowerPoint [14]	03/03/03
Deliver oral presentation [18]	02/04/03
13 - Project completion	02/04/03

Table 4.2.2. Project milestones and associated dates.

It is a requirement for this project to have agreed progress meetings, each of which will have a pre-determined agenda, and the minutes of which will be kept in the project file maintained by the students. The students and supervisor have agreed to meet on 3 occasions: 4 December 2002, 22 January 2003 and 19 March 2003.

4.2.3. Project budget

This project does not have industrial sponsorship at present although the department may pay for small items of expenditure, subject to approval. An estimate of costs has been provided in this section for completeness only.

Human resources

The supervisor has indicated to the students that the time spent on the project is expected to be 63 working days (7 hours per day), equivalent to 441 hours project work per project partner (Thornhill 2002c). The students have agreed to meet with the supervisor for one hour on a weekly basis during term time, equivalent to an additional 23 hours per project partner.

Figures B.1 and B.2 (Appendix B) show the weekly project timetable for term 1 and term 2 respectively, with the project hours shaded in grey, and the weekly meeting indicated in black. Furthermore, the figures show that during the 12 weeks of the 1st term the students will be working on project work for 18 hours a week, and similarly during the 11 weeks of the 2nd term the students will be working on project work for 22 hours a week. This comes to 458 hours in total, which is approximately equal to the number of hours of work indicated by the supervisor.

The students have also agreed to work a period of 3 hours on Sunday between 16:00 and 19:00 if the project work for that week over-ran. An additional consideration is that Seyed Ali Mirkhani will be taking an intensive module in the 2nd term, between Monday 18th February and Friday 14th March and this means that 3 weeks of regular project time will be lost. Seyed Ali Mirkhani has thus agreed to compensate for this in advance by working 3 weeks during the Christmas holidays.

Based on the human resources alone this project will cost £4,600 per student (460 hours at £10 per hour) and £1,500 per supervisor (50 hours at £30 per hour), coming to a total of £10,700.

Equipment and consumables

The majority of the work in this project will be software based and so the only large costs are for personal computers (one per project partner at £1,000 each) and software programmes (the cost of the Matlab license is £447). A book has already been purchased for the project at cost of $140. Additionally there are printing costs associated with the project, a maximum of £50.

The total cost for this project due to human resources, equipment and consumables is approximately £13,000.

4.3. Suggestions for supervisor

The project supervisor is required to provide the students with data from a US chemical plant and this data is expected to represent 30 measurements from two days of running the plant. It would be beneficial for the students that this data contained both normal and faulty plant signals so that the sonification of the data could clearly distinguish between the two modes of operation.

The students believe that this proposal demonstrates that the application of sonification techniques to chemical plant signals would provide control engineers with a valuable insight into the operation of the plant and would be a valuable tool in fault diagnosis. It would thus be advantageous if the supervisor could seek industrial sponsorship of the project so that the work could be practically demonstrated to control engineers that conduct these assessments visually and to obtain their insight into the facilitation of sonification on chemical plant data.

Many of the references in this report are from the proceedings of ICAD conferences and work done on this project would certainly interest the attendees of their forthcoming conference. The students would appreciate their work being presented at the forthcoming ICAD 2003 conference that will take place during 7-9 July at Boston University. The submission deadline is 31 January 2003 and this will mean that the project work would have to be completed by the students before the end of 2002 providing the supervisor with one month to review their paper.

5. CONCLUSIONS AND FUTURE WORK

A summary of the research work carried out in the field of sonification has been presented along with an overview of the advantages that the application of sonification to process data from a chemical plant would have. The purpose of this report was to present a review of the way in which the project could progress and this has been achieved through a critical discussion of the work that the project entails, an analysis of the project risk and the distribution of work between the parties involved in the project.

A brief review of direct sonification techniques has also been presented, revealing the promising method of frequency modulation. Additionally, it has also been highlighted that the limitations of Matlab beyond the realm of numerical analysis may be overcome by using the Sound API for Java.

5.1. Time plan and bar chart

The envisaged endpoint for the project is the satisfaction of the deliverables listed in table 1.4. The Gantt chart shown (figure 5.1) encapsulates all of the deliverables referred to in table 1.4 in the context of the planning of future work discussed in section 4.

6. REFERENCES

The references in this section are based on British Standards BS1629:1976 and BS5605:1990 with the exception of references to online material which has been formatted according to the American Psychological Association style.

Byrd, D. and Crawford, T., 2002. Problems of music information retrieval in the real world. *Information Processing & Management*, 38, 249-272.

Childs, E., 2001. The sonification of numerical fluid flow simulations. *In:* J. Hiipakka, N. Zacharov and T. Takala eds. *Proceedings of the 7th International Conference on Auditory Display*, 29 *July 29 – 1 August, 2001, Helsinki University of Technology, Espoo, Finland*.

Dobson, J.P., Thornhill, N.F., 2002. Analysis of plant-wide disturbances using conditional entropy. *In: IEEE Conference on Control Applications, 18-20 September 2002, Scottish Exhibition & Conference Centre, Glasgow, Scotland*.

Jarrel, J., 2002. Sonification module – some basic musical concepts. *In: West Virginia University Virtual Environments Laboratory, Online modules for VRML and Sonification.* Retrieved on 17 October 2002 from http://wvvel.csee.wvu.edu/sepscor/ sonification/lesson3.html

Kramer, G., 1994. An Introduction to Auditory Display. *In:* G. Kramer ed. *Auditory Display: Sonification, Audification, and Auditory Interfaces*. Santa Fe Institute Studies in the Sciences of Complexity, Proc. Vol. XVIII. Reading, MA: Addison Wesley, 1994, 1-77.

Kramer, G., Walker, B., Bonebright, T., Cook, P., Flowers, J., Miner, N.; Neuhoff, J., Bargar, R., Barrass, S., Berger, J., Evreinov, G., Fitch, W., Gröhn, M., Handel, S., Kaper, H., Levkowitz, H., Lodha, S., Shinn-Cunningham, B., Simoni, M., Tipei, S., 1999. The sonification report: Status of the field and research agenda, *Report prepared for the National Science Foundation by members of the International Community for Auditory Display.* Santa Fe, NM: ICAD.

Madhyastha, T.M. and Reed, D.A., 1994. A framework for auditory display design. *In:* G. Kramer ed. *Auditory Display: Sonification, Audification, and Auditory Interfaces*. Santa Fe Institute Studies in the Sciences of Complexity, Proc. Vol. XVIII. Reading, MA: Addison Wesley, 1994, 267-289.

Madhyastha, T.M. and Reed, D.A., 1995. Data sonification: Do you see what I hear?. IEEE Software, 12(2), 45-56.

Noirhomme-Fraiture, M., Scholler, O., Demoulin, C., Simoff, S., 2002. Sonification of time dependent data. *In: Proceedings of 2nd International Workshop on Visual Data Mining, 19-23 August 2002, Helsinki, Finland*.

Selviah, D., 2000.Technical project reports: a student guide. *Department of Electronic & Electrical Engineering, London, 10 April 2000*. Retrieved on 20 October 2002 from http://www.ee.ucl.ac.uk/~dselviah/ReportOutline.html

Sullivan, J., 1998. Bringing sound into the PC foreground. *In: Wired News, March 9, 1998*. Retrieved on 4 October 2002 from http://www.wired.com/news/print/0,1294,10792

,00.html

Sun Microsystems [Author unknown] 2002. Java Plug-in 1.4 Developer Guide Contents. Retrieved on 27 October 2002 from ftp://ftp.java.sun.com/docs/j2se1.4/ programmer_guide.pdf

Tannen, R.S., 1998. Breaking the sound barrier: designing auditory displays for global usability. *In: 4th Conference on Human Factors & the Web, 5 June 1998, Basking Ridge, NJ, USA*. Retrieved on 10 October 2002 from http://www.research.att.com/conf/hfweb/ proceedings/tannen/

Thornhill, N.F., Shah, S., Huang, B., 2001. Detection of distributed oscillations and root-cause diagnosis. *In: Proceedings of CHEMFAS 4, , Jejudo (Chejudo) Island, Korea, 7-8 June 2001.* 167-172.

Thornhill, N.F., Xia, C., Howell, J., Cox, J., Paulonis, M., 2002a. Analysis of plant-wide disturbances through data-driven techniques and process understanding. *In: 15th Triennial World Congress of the International Federation of Automatic Control, Barcelona, Spain, 21–26 July 2002*.

Thornhill, N.F., 2002b. Sonification of process data – The Singing Plant. *Department of Electronic & Electrical Engineering, London, 18 August 2002*.

Thornhill, N.F., 2002c. Presentation on 4[h] year project. *Department of Electronic & Electrical Engineering, London, 24 October 2002*.

Wilkie, G., 1993. *The Studio Musician's Jargonbuster.* London: Musonix Publishing

APPENDIX A DRAFT PROJECT RISK ASSESSMENT

DEPARTMENT OF ELECTRONIC & ELECTRICAL ENGINEERING

PROJECT RISK ASSESSMENT

PROJECT TITLE: **The Singing Plant**

The following research workers and/or students will be involved in the project:

NAME	**QUALIFICATIONS/STATUS**
NINA, THORNHILL	Project Supervisor
CHENG, HOE YEUNG	4th year MEng EE/MS Project Student
MIRKHANI, SEYED ALI	4th year MEng EEE Project Student

I have considered the risks associated with the above project during the coming year and confirm that they are covered by the following Codes of Practice.

1. ACCIDENT REPORTING, http://www.ee.ucl.ac.uk/~omed/A1.html, Department Safety Page. Any accident or 'incident', including near misses, whether or not there are apparent injuries, and ill health arising as a result of work activities will be reported to the Departmental Safety Officer who will ensure that a College Accident Report Form is completed and passed to the College Safety Office.
2. AFTER HOURS AND LONE WORKING, http://www.ee.ucl.ac.uk/~omed/A2.html, Department Safety Page. Laboratory work will only be performed during normal working hours which are defined as 8am to 6.30pm, Monday to Friday.
3. FIRE, http://www.ee.ucl.ac.uk/~omed/fire.html, Department Safety Page. If a fire is discovered, people in the vicinity aware of the danger will be notified immediately. The fire service will then be phoned on emergency 222 . Room location, floor number and that this is Building 9 will be stated.
4. SMOKING, EATING AND DRINKING, http://www.ee.ucl.ac.uk/~omed/smoke.html, Department Safety Page. Smoking in all other areas of the Department is prohibited. This includes corridors and stairwells.

I confirm that the work will be carried out in accordance with these Codes of Practice and the Department Safety Regulations.
The College Laser Safety Officer has been notified of any work involving lasers.
I undertake to inform the Departmental Safety Officer of any additional foreseeable risks which may arise during the year.

If any risks are not covered in existing Codes of Practice or the Departmental Safety Regulations then state below what precautions will be taken to protect (a) experimental personnel involved; (b) maintenance and other personnel who might enter the laboratory in pursuit of their duties; (c) other College personnel including students.

1. RADIATION OF DISPLAY MONITOR, Project students are not advisable to stare into the monitor screen for long period of time as it may affect eyesight. A short break of 5-10mins will be beneficial for the eyes. Massaging of the eyes can also be carried out during the break time to relax them.
2. SITTING POSTURE, Due to the predicted long period of time in front of the computer screen, wrong sitting posture may affect the spine. Project students are advisable to sit in a correct sitting posture.

This assessment will be reviewed not later than 9 months.

____________________ ____________________

Date Academic Member of Staff

APPENDIX B DIRECTMT.M

```
% directMT.m - Analysis of sonification using different modulation tecniques
% 16/10/02 Seyed Ali Mirkhani

load f0526sht.txt
err1 = f0526sht(:,2)-f0526sht(:,1);  % sp minus pv
err1 = err1/(max(err1)-min(err1)); %scaling
figure(1), clf reset
figure(1), plot(err1)
title('Scaled and interpolated error signal'), xlabel('Data sample'), ylabel('Magnitude of error signal')
err1interp = interp(err1,200); % interpolation to make more samples

sample_am = modulate(err1interp,350,22000,'am'); %AM encoding
pause
figure(2), clf reset
figure(2), plot(sample_am)
title('Amplitude modulated error signal'), xlabel('Data sample'), ylabel('Magnitude of amplitude modulated error signal')
sound(sample_am*0.1,22000) %play the sound

sample_fm = modulate(err1interp,440,22000,'fm',0.2); %FM encoding
pause
figure(6), clf reset
figure(6), plot(sample_fm), title('Frequency Modulation')
sound(sample_fm*0.1,22000) %play the sound

sample_pm = modulate(err1interp,440,22000,'pm',6.1); %PM encoding
pause
figure(7), clf reset
figure(7), plot(sample_pm), title('Phase Modulation')
sound(sample_pm*0.1,22000) %play the sound
```

APPENDIX C PROJECT TIMETABLES

Time	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	
10:00					
11:00					
12:00					
13:00					
14:00					
15:00					
16:00					
17:00					
18:00					
Total Project Hours	5	5	5	3	18

Figure B.1. Term 1 weekly project timetable, with cells shaded grey indicating project hours and black cell indicating project meeting.

Time	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	
10:00					
11:00					
12:00					
13:00					
14:00					
15:00					
16:00					
17:00					
18:00					
Total Project Hours	3	7	5	7	22

Figure B.2. Term 2 weekly project timetable, with cells shaded grey indicating project hours and black cell indicating project meeting.