ON THE ROAD TO DESIGN: DEVELOPING A SONIFIED ROUTE NAVIGATOR FOR CYCLISTS

Andrew Moulster

British Telecom PLC
Andy.moulster@btinternet.com

Tony Stockman

Interaction Media and Communication
& Centre for Digital Music
School of Electronic Engineering and Computer Science
Queen Mary University of London
tony.stockman@eecs.qmul.ac.uk

ABSTRACT

This paper describes the development of a system that uses sonification to assist cyclist's navigation. The focus of the paper is on the design process, the decisions made and the methods used to make design choices. An important aspect was the use of listening tests undertaken by potential users of the system while cycling in order to obtain data used to underpin key design decisions regarding the timing and representation of route elements. The architecture and usage of the developed system is described, as well as details of on and off road evaluations of the system.

1. INTRODUCTION

Recreational cycling has experienced a massive surge of popularity over the last five years or so. Many factors have contributed to this:

• Incentives such as the UK government's Cycle To Work scheme which was launched in 2005 to reduce the cost of purchasing a bike for commuting to work.
• The rise in the number of cycle shops (including online stores) providing more choice and competition
• Charities such as Sustrans [25] promoting a healthier lifestyle by encouraging families to cycle recreationally and for children to cycle to school (Bike It Scheme in the UK).
• Technological advances and improved manufacturing techniques have made bikes lighter and more enjoyable to ride.

As a result, there are more cyclists commuting during the week and, having improved their confidence and level of fitness, they want to cycle further at the weekend. They plan their routes beforehand and either rely on memory to navigate their route or they take a map with them. Others use GPS devices such as the Garmin Edge [8] range or Apple's iPhone running one of the numerous cycling applications [15]. These devices strap to the handlebars and provide visual cues to indicate the change of direction to the rider at the appropriate time. These devices generally have small screens and therefore limited ability to display navigational information.

Unfortunately for cyclists, visual displays are passive devices, which have to be checked frequently to see if they have been updated. This not only has safety implications, it can also be difficult to see in rain, low light and bright sunny conditions. Even bikes with sophisticated suspension cannot prevent the GPS device from vibrating, making the display very difficult to read irrespective of the lighting conditions.

One of the pleasures of leisure cycling is the time it allows the cyclist to view their often-picturesque surroundings. However, in order to avoid missing a turning, much of the cyclist's time must be spent monitoring the GPS device's display.

Sound is an active medium with the cyclist playing a passive role. According to (19), auditory displays provide an additional means of communication for devices with small screens such as PDAs or mobile phones. Using sound to navigate allows them to concentrate on cycling and to enjoy the ride. The Kapten Personal GPS Voice Navigator [19] goes some way to addressing the visual feedback issues mentioned above, as it is an audio only navigator, but as its name suggests, relies solely upon vocal directional feedback. Users need to be able to understand the navigator's language and external factors such as traffic and wind noise restrict the user's ability to hear what is being said. The sound output of an auditory display need not be verbal. In fact well-designed non-verbal sound information has the potential benefit of being relatively easy to learn by people of any language.

This paper describes the development of a GPS based navigational device, which we will refer to as a navigator, which provides audible directional feedback to the user in the form of non-verbal sound only (sonification). It will be primarily designed with the cyclist in mind but could be used by anyone wishing to navigate a predetermined route with normal hearing. Consequently, this device could be of value to visually impaired users too.

2. RELATED WORK

2.1 Audio displays for vehicular navigation

Mantel et al. (28) described the prototyping of Navinko, a social network and navigation system including audio augmented reality for cyclists in Tokyo. It uses mobile devices to store and share users' landmarked Points Of Interest (POI) and interact with other riders while attempting to instigate new types of social behavior, such as clustering the users into bikepools for increased comfort and safety.

Jeon et al. (29) describe the design of a system, which uses audio to compliment a visual display of turning points for car drivers. The auditory display consists of voice announcements of upcoming turns panned in the direction of the turn, and a succession of tones of increasing volume to assist drivers in anticipating the time at which to make the turn. They make the point that "Drivers have to decide which lane they will turn into, depending on the next turning direction after the current one", and therefore that "For drivers, multiturn planning needs to be part of the instructions, and presented before the first turn, in order for adequate sequencing of subgoals". As described in (30), many previous systems that use audio as part of a mobile display focus on prerecorded or user-recorded data, or use a text to speech engine.

2.2 Considerations for a mobile navigational device

2.2.1 Effective communication of direction change

The unambiguous nature of Patterson's pacenotes [18] have enabled them to be regarded as one of the preferred methods of effectively navigating rally cars over a wide range of terrains and courses for many years. Pacenotes are a form of code used by the navigator and driver in a car rally competition to safely negotiate bends and turnings at speed. When a direction change is required, the navigator calls out a description of the turn ahead which is recorded on the pacenotes before the rally stage has started. This informs the driver of the severity of the direction change and the appropriate speed to take. Each turn is given a rating according to its severity.

The pacenotes consist of 20 distinct directions relative to the current direction of travel: 10 to the left and 10 to the right forming a mirror image. The directions range from a slight deviation from the current course to a hairpin and then acute angle.

Variations on the theme are used depending upon personal preference but all are based on the same 20-point system. Bends and turnings in the road can occur at any angle and often at short notice to the rally driver due to the speed at which they drive. They often force the rally driver to change course by an unknown amount if they had to rely on vision alone. Driver visibility is sometimes poor due to weather, road and vehicle conditions and the topography of the course. The driver relies heavily on the navigator to provide clear, concise speed and direction commands at the right moment to enable the direction change to be executed safely and as fast as possible.

The 20-point system adopted by Patterson and shown below reduces the possibility of auditory overload for the driver. The variations in the system allow the driver and navigator to select which they find preferable.

The eight variations are: Numbers, Descriptive, Six Fastest, Six Fastest – Number First, Finlay System, 1-9 System, Direction First, Swedish System.

Number Variation		Descriptive Variation	
R.....Right 1R.....One 2R.....Two 3R.....Three 4R.....Four	5R.....Five 6R.....Six SqR.....Square HpR.....Hairpin AcR.....Acute	R.....Right ER.....Easy FR.....Fast FMR.....Fast Mid MR.....Mid or Medium	KR.....Kay 6R.....Six SqR.....Square HpR.....Hairpin AcR.....Acute

Table 1: Two of the 8 Patterson's pacenote variations showing commands from just right of straight ahead to acute right

2.3 Global positioning system - GPS

The Global Positioning System (GPS) is a US based utility that provides continuous, worldwide positioning, navigational and timing (PNT) service freely to anyone who has a GPS receiver. According to the National Space-Based Positioning, Navigation, and Timing Coordination Office (http://www.gps.gov/) the GPS is made up of three parts, two of which (space and control) are owned by the US Air Force:

• Space

According to Dana [5], at the time of writing, 24 satellites orbit the earth transmitting the current satellite positioning data and time. The satellites are positioned at approximately 60 degrees separation to ensure that between 5 and 8 of them are visible from any point on Earth.

• Control

Worldwide control centre's monitor and communicate with the satellites to make sure they are synchronized, are sending reliable data and are healthy. They update the satellites with changes to navigational data and maneuver the satellites where necessary.

• User

GPS receiver equipment, which receives, signals from the GPS satellites and calculates the user's three dimensional position (latitude, longitude, altitude) and time.
Each receiver requires four GPS satellite signals to accurately calculate its position within a few meters [5].

3. ROUTE NAVIGATOR SYSTEM

3.1 System concept

The cyclist plans a route using one of the many route planners available on the Internet. For this project, we have used mapmyride.com. The plan of the route can be on-road, off-road or a mixture of the two, and once completed, it can be downloaded in GPS Exchange Format (GPX) and then imported into the navigator.

The navigator application runs on a mobile phone capable of supporting the Java ME platform and having Bluetooth functionality. It has a simple display, which allows the cyclist to import a route, start, stop, adjust the volume and advance the navigator to the next waypoint. The functions of the auditory display involve:

- Playing non-verbal sounds at appropriate intervals to indicate how much a cyclist needs to deviate from their current course in order for them to reach the next waypoint.
- Inform the cyclist when a waypoint has been reached.

3.2 Listening tests to inform the sonification design

3.2.1. The aim

For the project to be a success, it was essential that the sounds be designed to be clearly audible and distinguishable within the bike-riding context. To achieve this, a controlled experiment was necessary to determine which sounds to use and the minimum interval that can be perceived between the sounds. It is vital that audible feedback is heard by the cyclist in a number of different cycling environments and that the feedback does not prevent the cyclist from detecting important ambient noises such as traffic sounds. A group of testers were invited to listen to a series of sounds whilst cycling in different environments and recording their findings in a questionnaire.

3.2.2. Participants

Firstly, we determined that the target population for the experiment needs to meet the following criteria:

1) They have a reasonable level of hearing.
2) They have access to a bicycle.
3) They have access to a portable listening device (mp3 player or similar).
4) They are prepared to cycle while listening to a portable listening device.
5) They have access to a cycling environment.

As these prerequisites are fairly basic and no experience of acoustics or musical ability is necessary, the target population is very large.

3.2.3. Determining dependent and independent variables

As the testing was to be carried out on a bicycle, the amount of quantitative data that the tester is able to retain at any one time is small. It is of course not practical or safe for the tester to record data as they cycle. Therefore, a questionnaire was designed with this in mind and the tester was only required to retain three pieces of quantitative data at a time:

1) The number of sounds per track.
2) The number of single tones.
3) Which sounds had single tones.

The remaining questions were qualitative and could be answered at the end of the testing.

Variable no	Dependent variable	Value
v1	Sounds with single tones	1-7
v2	The annoyance value of a track	1-5 (1=not annoying, 5=very annoying)
v3	Player volume per track	1 – 10 (1=minimum, 10=maximum)
v4	The preferred instrument	clarinet/piano/violin
v5	Note length too short?	y/n
v6	Note length too long?	y/n
v7	Comments	free text

Table 2: Dependent variables

Variable no	Independent variable	Value
v8	Environment	noisy road/quiet road/off road
v9	Road condition	dry/wet
v10	Cycling speed	mph

Table 3: Independent variables

3.2.4. Hardware and software requirements

The tracks that the testers were to test were in mp3 format so each personal listening device needed to support this audio format. Each tester was provided with 2 questionnaires and instructions on how to go about the tests.

3.2.5. Procedure

The tester's task is to listen to 6 tracks under varying conditions. Each track contains 7 sounds and each sound is made up of 2 notes (or tones) played by an instrument. All notes within a track are played by the same instrument. The pitch and interval between notes varies although the interval is never greater than 1 second so the tester can pair the notes. Each track's lead in varies and is greater than 10 seconds to let the tester put the player in their pocket and start cycling.

At the end of the track, the tester stops cycling, pauses the player and records the sound and tone information along with the player volume and speed if known. They then repeat the experiment under a different condition. 2 tracks contain piano notes, 2 clarinet notes and 2 violin notes. We chose these instruments because of their clean timbre.
Track Contents

Instrument	Sound 1	Sound 2	Sound 3	Sound 4	Sound 5	Sound 6	Sound 7
1. Clarinet	F#4 0.375	C2 1.0	C2 1.0	E♭4 0	E♭2 1.0	E♭2 1.0	C7 1.0
2. Clarinet	F#4 0.25	C7 1.0	C4 0	F#4 0.125	A4 0	A6 1.0	A6 1.0
3. Piano	F#4 0.375	C2 1.0	C2 1.0	E♭4 0	E♭2 1.0	E♭2 1.0	C7 1.0
4. Piano	F#4 0.25	C7 1.0	C5 0	F#4 0.125	A4 0	A6 1.0	A6 1.0
5. Violin	F#4 0.375	C2 1.0	C2 1.0	E♭4 0	E♭2 1.0	E♭2 1.0	C7 1.0
6. Violin	F#4 0.25	C7 1.0	C4 0	F#4 0.125	A4 0	A6 1.0	A6 1.0

Table 4: Track contents for sound usability experiment

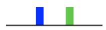
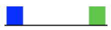
Key	
 C2 0.375	Note duration = 0.125 seconds Deviation note (green) = C2 Interval between notes = 0.375 seconds Blue note = reference tone = F#4
 A6 1.0	Note duration = 0.25 seconds Deviation note (green) = A6 Interval between notes = 1.0 seconds Blue note = reference tone = F#4

Table 5: Key for track contents table

We designed the tracks to test 4 factors:

1) The minimum perceived duration between notes.
2) The minimum perceived pitch change.
3) Whether a high or low note can be heard.
4) The minimum suitable note duration.

Sound 4 is designed to test factors 1 and 2 as the interval is 0 or one eighth of a second. E♭4 is only 3 notes lower than the reference tone F#4. Sound 1 tests factor 1 only because both notes are the same. Sounds 2, 6 and 7 test factor 3 with differing note durations. Sounds 3 and 5 tests factors 2 and 3. C4 and C5 are 6 notes away from F#4 and A4 is 3 notes away (factor 2), while C2 is the note of lowest pitch tested (factor 3). The tracks only contained 7 sounds to minimise the quantity of data that the tester had to retain.

Factors being tested were slightly jumbled to minimise the confound caused by the tester forming a pattern and predicting which note is coming next. Tracks only contain one instrument in an attempt to simulate what the user of the navigator will experience and helps the tester to make a judgment about each instrument's annoyance value.

3.2.6. Analysis

9 people participated in the testing. 4 people tested 2 environments (quiet and noisy road), 2 tested quiet road only and 3-tested busy road only. Variables 5, 6 and 9 were constant throughout the results [N, N and Dry] so we removed them to simplify the data. Preferred instrument, comments and track annoyance value are qualitative variables so these need to be looked at separately. 6 tests were carried out on a quiet road at a gentle speed and all sounds were heard with the player volume at approximately 60% maximum. 7 tests were carried out on a noisy road at a moderate pace (approximately 15 mph) and with the player volume set at or near maximum. The following table shows the results:

Track	Sound 1	Sound 2	Sound 3	Sound 4	Sound 5	Sound 6	Sound 7
1. Clarinet		5	4		3	2	
2. Clarinet		2					
3. Piano		5	4		1	2	2
4. Piano	1	2		3		2	2
5. Violin	1	5	5	1	5	4	1
6. Violin						1	

Table 6: How many times both notes were not heard in a busy road environment

From the above table, we categorised the 63 failures into 2 tables:

Note failure analysis				Interval failure analysis			
Note	Failures	Note total	%	Interval*	Failures	Sound total	%
C2	28	42	66.67%	0	1	63	1.59%
E♭2	17	42	40.48%	0.125	3	21	14.29%
C4	0	14	0.00%	0.25	1	21	4.76%
E♭4	1	21	4.76%	0.375	1	21	4.76%
F#4	5	63	7.94%	1	57	168	33.93%
A4	0	21	0.00%				
C5	0	7	0.00%				
A6	5	42	11.90%				
C7	7	42	16.67%				*seconds

Table 7: failure analysis for notes and note intervals in a busy road environment

From table 7, we concluded that the interval between notes is not an issue for cyclists.

Clearly people have no problem in detecting intervals of 1 second in length so the 57 failures must be caused by other factors. Interestingly, 6 interval failures (blue) occurred with sounds containing notes in the middle of the audible range and are a very small percentage of the total interval count (2.04%). We therefore regarded these results as anomalies and could have been caused by the miscounting of sounds or an error in recording the results by the testers. Although the 3 sound 4 failures may show that piano notes played close together are difficult to hear.

So the remaining results show a weighting towards the low-pitched notes which indicates that the middle note F sharp 4 should be revised upwards and the highest and lowest notes removed. The poor results for notes with low frequencies are probably partly due to interference from the background traffic noise, which tends to be at the lower end of the audible frequency range. We made the reference tone the note C5 as a result of the testing.

Note Duration Analysis

Notes of 0.125 second duration had 34 failures compared to notes of 0.25 second duration which had 29 failures. This small difference in failures suggests that 0.125 seconds is not too short and could be used to create a lookahead of short duration.

Choosing instruments for reference and deviation tones

Table 8 shows the total annoyance scores for the 3 instruments. The lowest score is the least annoying. Clearly, the violin is the most annoying so this instrument should not be used.

Instrument	Annoyance score
Clarinet	7
Piano	10
Violin	28

Table 8: Annoyance score

Clarinet note failure analysis				Piano note failure analysis			
Note	Failures	Note total	%	Note	Failures	Note total	%
C2	9	14	64.29%	C2	9	14	64.29%
Eb2	5	14	35.71%	Eb2	3	14	21.43%
C4	0	7	0.00%	C4	0	0	0.00%
Eb4	0	7	0.00%	Eb4	0	7	0.00%
F#4	0	21	0.00%	F#4	4	21	19.05%
A4	0	7	0.00%	A4	0	7	0.00%
C5	0	0	0.00%	C5	0	7	0.00%
A6	0	14	0.00%	A6	4	14	28.57%
C7	2	14	14.29%	C7	4	14	28.57%

Table 9: Instrument failure analysis

From table 9, it can be seen that the piano had 8 more failures, 6 being at the higher end of the scale. For this reason, we made the piano play the mid range C5 reference tone and the clarinet play the wide range of deviation tones. Interval durations between notes turned out to be irrelevant due to hardware limitations but findings may be useful in future work. The 4 piano failures in blue suggest that it may be difficult to distinguish 2 piano notes played close together.

4. DESIGN

The overall design approach used involved iterating a series of prototypes, which were refined using feedback from users and taking into account the physical constraints of the mobile device. In addition to the auditory interface, it was necessary to develop a visual interface for 3 reasons:

1) To help test the navigator
2) To enable the cyclist to use the device when they are not able to hear the audible output
3) To enable demonstration of the navigator

4.1 Feedback structure

We initially wanted to base the direction change values on the 20 directions provided by Patterson's Pacenotes [18]. The 21st note being straight ahead. Each angle of deviation is represented by a pitch or note of an instrument. The lowest pitch would represent an acute left (AcL) direction change through to the highest pitch representing acute right (AcR). No direction change would be represented by the middle note F#4. However, in practice, it is not necessary to have this number of notes and the range of notes had to be amended as shown in table 10 below to prevent auditory overload and interference problems. The most significant change is the increase in range of the "on course" note, which now has a range of 39 degrees. This is due to the fact that the cyclist is rarely exactly on course and a margin of error of this size is required to prevent the cyclist from incorrectly believing that a direction change is needed.
The on course note was revised from F#4 to C5 based on the results of the sound suitability study.

Despite the results of the user testing indicating that notes of relatively short duration could be suitable for sonifications, the hardware limitations of the mobile device prevented the creation of a short and concise lookahead. Therefore, to increase the usability of the navigator, we decided to set the note duration at 0.5 seconds.

Original frequency mapping		Intermediate frequency mapping		Final frequency mapping	
Bearing range (degrees)	Note	Bearing range (degrees)	Note	Bearing range (degrees)	Note
180 - 222	C2				
223 - 252	Eb2				
253 - 274	F#2	180 - 222	F#2		
275 - 286	A2	223 - 252	A2		
287 - 299	C3	253 - 274	C3		
300 - 312	Eb3	275 - 286	Eb3		
313 - 326	F#3	287 - 299	F#3		
327 - 340	A3	300 - 312	A3		
341 - 351	C4	313 - 326	C4		
352 - 358	Eb4	327 - 340	Eb4	180 - 240	Eb4
359 - 001	F#4	341 - 019	F#4	241 - 290	F#4
002 - 008	A4	020 - 033	A4	291 - 340	A4
009 - 019	C5	034 - 047	C5	341 - 019	C5
020 - 033	Eb5	048 - 060	Eb5	020 - 069	Eb5
034 - 047	F#5	061 - 073	F#5	070 - 119	F#5
048 - 060	A5	074 - 085	A5	120 - 179	A5
061 - 073	C6	086 - 107	C6		
074 - 085	Eb6	108 - 137	Eb6		
086 - 107	F#6	138 -179	F#6		
108 - 137	A6				
138 - 179	C7				

Table 10: Modifications to the frequency – bearing mapping

4.1.1. Representing direction change

To overcome the transience of information problem, each feedback iteration or beat starts with a brief reference tone. This reference tone's frequency is fixed (the middle note C5) but would be played by a different instrument to the direction change notes. This prevents the two tones from being confused and signifies the start of a new beat. The reference tone is followed after a brief period of silence by a deviation tone whose frequency indicates how the cyclist needs to steer to keep on track as figure 1 illustrates.

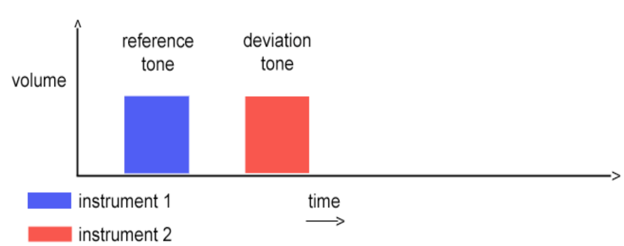


Figure 1: Tones played when arrival at the next waypoint is not imminent

After another brief period of silence, the cycle repeats with another reference tone. During beta testing it became evident that the beat frequency when on track (deviation note = reference note) was too high and was causing annoyance to the cyclist. In this situation, the delay between beats was extended to 10 seconds providing that the next waypoint was at least 23 seconds away.

4.1.2. Handling an approaching waypoint

A route contains waypoints each of which mark a change in direction of travel. For a cyclist to navigate a route effectively, they need to be alerted as they approach a waypoint and not when they arrive at it. When the cyclist is less than period T seconds from the next waypoint at their current speed, the deviation tone is replaced by a note, which represents the deviation from that waypoint to the next waypoint along the route. This pre-warning gives the cyclist time to make the direction change and not overshoot the waypoint as figure 2 illustrates.

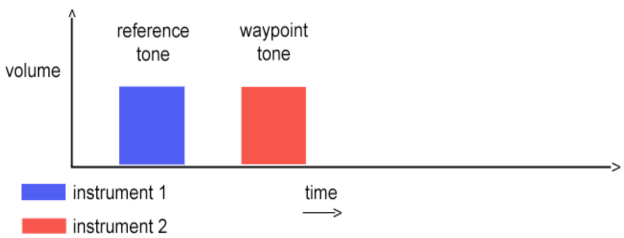


Figure 2: Tones played when arrival at the next waypoint is imminent

4.1.3. Handling a twisty section of route

Despite the pre-warning of waypoints in section 4.1.2, the navigator may still be unable to respond quickly enough to inform the cyclist of a number of closely situated waypoints such as those that could occur at a roundabout or chicane. The navigator therefore needs to perform a lookahead action on each beat. This involves the creation of a mini route (or lookahead), which contains all waypoints reachable in time by the cyclist travelling at the current speed. After the reference and deviation tones are played, the lookahead route is played to the cyclist in a similar way to approaching a waypoint. This enables the cyclist to build a picture in their mind of the route immediately ahead.

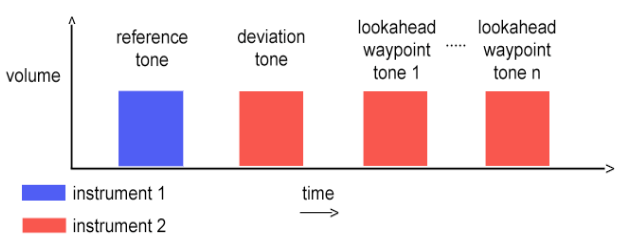


Figure 3: Tones played when the lookahead contains n waypoints

If the lookahead contains waypoints and the cyclist is within alert range of the next waypoint, figure 3's deviation tone is replaced by a waypoint tone.

4.1.3. The end of the route

When the last waypoint has been reached, the sounds stop playing. To navigate another route, the application needs to be closed down and run again.

4.2 System usage

- The cyclist creates a route at mapmyride.com and saves it to their computer as a route.gpx file (outside of system).
- The cyclist copies the route.gpx file to the mobile device folder that contains the route navigator (outside the system).
- The cyclist runs the navigator on their mobile device.
- Starting the navigator causes the GPX file to be opened and loaded into the navigator to create a route.
- Once the route is created, the navigator attempts to connect to the GPS receiver.
- The navigator continuously reads GPS data from the GPS receiver to enable the traveler to traverse the route.
- A traveler is created by the navigator, which traverses the route according to the GPS data received.
- The cyclist manually advances the traveler to the next waypoint on each button press.
- Increases the volume of the tones until the maximum level is reached.
- Decreases the volume of the tones until the minimum level is reached.
- Exits the navigator.

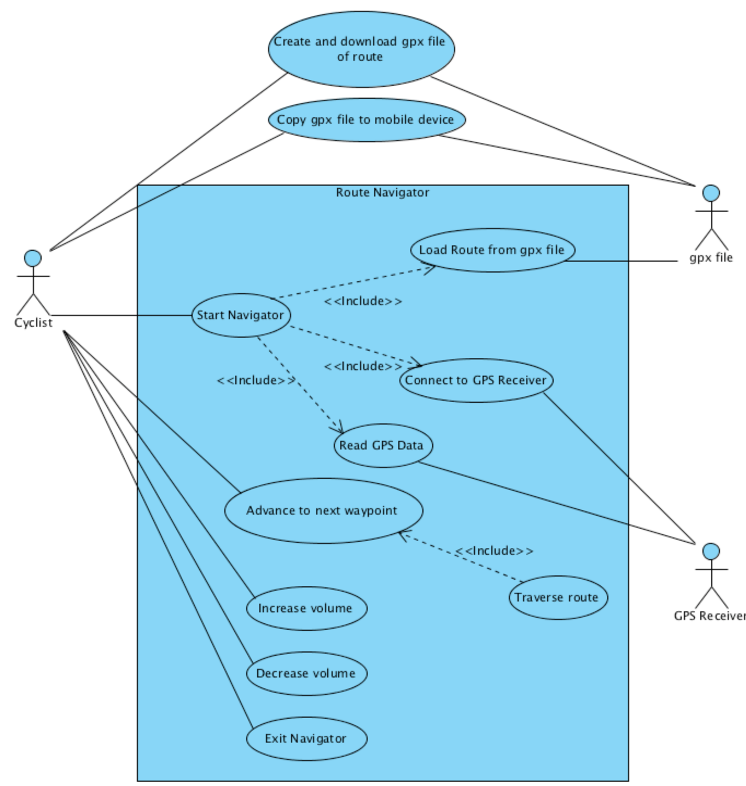


Figure 4: Use case diagram for navigator system

5. PROTOTYPING

5.1 Alpha testing

As stated in section 4, the development lifecycle involved creating a quick and simple design, which was then implemented, tested and released, in small increments. One of the authors was the only alpha tester and testing involved navigating small local routes by foot and bicycle to ensure that the latest implementation worked correctly before further redesign. As bugs were identified, they were recorded and fixed in coding. Once the navigator was accurately displaying directional changes needed for the cyclist to reach the next waypoint, we could be confident that the deviation algorithms were working correctly which enabled us to implement the debug mode and testing could be carried out much more efficiently on a desktop mobile phone emulator. However, at the same time, alpha testing was also carried out on a bike, as changes to the design were needed to make sure the timing of the audible feedback was correct. It was this on bike testing that triggered the introduction of the lookahead and the advance button.

5.2 Beta testing

We asked several people to carry out beta testing of the navigator once we were confident that as many of the bugs as possible were removed. This testing was carried out off road at first to allow the tester to devote much of their concentration to learning the sonifications. Minor timing modifications were made to the navigator to address issues raised during beta testing. The most notable change being the increase in the on track beat delay. The beta testing process was as follows:

1) We created a test route of approximately 1 mile in length using MapMyRide which we downloaded to the Samsung G600 mobile phone and renamed route.gpx. The testers were given no information about the route before testing.
2) Testers were given instructions on how to use the navigator and were given an idea of the audio feedback to expect and how to react to it.
3) The testers started the navigator after the Holux GPS receiver had been switched on and had obtained a satellite fix.
4) As the navigator relies upon movement to obtain a current bearing, we advised the tester which direction they should start. (This seemed reasonable as we would expect a cyclist to at least know which direction they would be heading at the start of a route if they had plotted the route themselves). We could have chosen not to give this information and made the tester guess a starting direction. They would soon deduce which direction is correct based on the audible feedback but we decided this introduced an unnecessary complication.
5) We followed the tester along the route at a short distance, noting any comments they made and giving no directional clues.

6. CONCLUSIONS AND FUTURE WORK

Despite all the key requirements being met, the navigator can be greatly improved not only by implementing additional requirements but also by exploring other implementation platforms.

The Samsung G600 mobile phone is very resource limited and we felt that during this project, the phone was often on the limit of its capability. Many more mobile devices are becoming GPS enabled and some GPS receivers such as the G-Fi GPS router [20] can communicate via WIFI which could be a much more reliable platform. The lookahead does overcome some of the issues that a twisty section of route poses. However, the large gap between the tones can make the lookahead sequence of tones rather long at 5-6 seconds for a lookahead containing 5 waypoints. It is not easy for a cyclist to retain this amount of information over this period. While Streaming MIDI is much more controllable as it does not require multiple players to play different tone sequences and hence can play tones much closer together in time. However, Java ME does not support streaming MIDI but other platforms may be able to.

In addition, alpha and beta testing has shown that common topographical features such as roundabouts and chicanes have a distinct audible fingerprint. It may be possible to simplify the lookahead when approaching a roundabout for example to provide one "right turn at roundabout" sonification instead of multiple left, right, right, right, left sounds.

As the navigator relies upon the cyclist's movement to determine their direction, after a cyclist has made a direction change, they will continue to get out of date directional feedback for 5-6 seconds. There is no obvious solution to this so further work is required to remove this redundant information. However, while performing alpha and beta testing, we quickly learnt to ignore this feedback.

Our analysis in section 4.1 shows that people can detect two different tones with intervals as small as one eighth of a second. This opens up the possibility of creating an advanced user mode, which creates a sound map of the route ahead. This map could contain waypoints that the cyclist can reach in 5 minutes for example if they continue at their current speed. More research is needed in this area as novice users would find it difficult to translate these tones. However, over time, more advanced users may be able to use the sound map to hear the way ahead.

The navigator can also be enhanced to include some of the standard features currently available in many navigational devices such as route recording for post ride analysis.
Beta testing results were very encouraging with all test routes being successfully navigated and with very little time needed to learn the sonifications.

The ability to navigate without maps or a display has huge potential for both visually impaired and eyes busy people. Whether the feedback mechanism is audio or haptic is down to personal preference but we believe the ability to navigate over a terrain that could be as diverse as the Sahara desert or the Antarctic is incredibly exciting.

7. REFERENCES

[1] Blattner, M., Sumikawa, D., & Greenberg,R. 1989. Earcons and icons: Their structure and common design principles. *Human Computer Interaction*, 4(1), pp11-44.

[2] Brewster, S.A., 2003., *The Human-Computer Interaction Handbook, Fundamentals, Evolving Technologies and Emerging Applications.* Lawrence Erlbaum Associates. Chapter 12: non-speech auditory output. p220.

[3] Carless, R. (2006). *Nokia.com Community Developer Discussion Boards – Thread: Maths - acos, asin, atan.* [Online] Available at: http://discussion.forum.nokia.com/forum/showthread.php?t=72840 [Accessed 15 February 2010]

[4] Cockos Inc. 2010. *Reaper v3.301 downloads.* [Online] (Updated 13 February 2010) Available at: http://www.cockos.com/reaper/download.php [Accessed 14 February 2010]

[5] Dana, P., 1994. *Global Positioning System Overview*. [Online] (Updated 5 Jan 2000) Available at: http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html [Accessed 10 October 2009].

[6] Fenton, NE., 2007. *Improving Your Technical Writing Skills Version 5.0.* London: Queen Mary (University, of London).

[7] Frauenberger, C., Stockman, T. & Bourguet, M., 2007. *A Survey on Common Practice in Designing Audio in the User Interface*, proceedings of HCI'2007. Lancaster: ISBN 978-1-902505-94-7, pp 187-195.

[8] Garmin Ltd. 2010. *Garmin Edge Bike Computers.*[Online] Available at: https://buy.garmin.com/shop/shop.do?cID=160 [Accessed 30 March 2010]

[9] Getjar. 2009. *Samsung SGH G600 Specifications.* [Online] Available at: http://stats.getjar.com/device/Samsung/SGH_G600 [Accessed 2 September 2009]

[10] Google. 2009. *Google Maps.* [Online] Available at: http://maps.google.com/ [Accessed 30 September 2009]

[11] Haptimap. 2010. *Workshop Pervasive 2010 - Multimodal Location Based Route Navigator Using Sonification Techniques for Extreme Navigation* [Online] (Updated 18 December 2009) Available at: http://www.haptimap.org/events/organized-events/pervasive.html [Accessed 30 March 2010]

[12] Holux. 2009. *M-1200 Wireless GPS Receiver Specifications.* [Online] Available at: http://www.holux.com/JCore/en/products/products_spec.jsp?pno=227 [Accessed 1 October 2009]

[13] Independent Living Aids. 2010. *Kapten Personal GPS Voice Navigator.* [Online] Available at: http://www.independentliving.com/prodinfo.asp?number=240460 [Accessed 30 March 2010]

[14] Kramer, G. et al., 1998. The Sonification Report for the Status of the Field and Research Agenda. International Community for Auditory Display (ICAD)

[15] La Rueda Tropical. 2010. *iPhone Cycling Applications.* [Online] (Updated 11 February 2009) Available at: http://ruedatropical.wordpress.com/2009/02/11/iphone-cycling-applications/ [Accessed 30 March 2010]

[16] MapMyFitness. 2009. *MapMyRide.com Login.* [Online] Available at: http://www.mapmyride.com/ [Accessed 2 September 2009]

[17] MIDI Manufacturers Association Incorporated. (n.d.). History of MIDI. [Online] Available at: http://www.midi.org/aboutmidi/tut_history.php [Accessed 15 October 2009]

[18] Patterson Agencies. 2003. *Patterson Pacenotes.* [Online] (Updated 16 February 2006) Available at: http://www.rallynews.net/oldsite/htdocs/notes/ [Accessed 12 October 2009]

[19] Perez C. et al., 2008. *HCI Beyond the GUI: The Human Factors of Non-traditional Interfaces, Morgan Kaufman. C*hapter 5: Auditory Interfaces.

[20] PosiMotion LLC. 2009. *G-Fi The World's First Mobile Network/GPS Router.* [Online] Available at: http://www.g-fi.com/ [Accessed 23 March 2010]

[21] Sinnott, R.W., 1984. Virtues of the Haversine, *Sky and Telescope*, 68(2), p159 -47 of 50- Route Navigator Using Sonification

[22] Sun Microsystems. 2009. *Java ME Technology APIs & Docs.* [Online] Available at: http://java.sun.com/javame/reference/apis.jsp [Accessed 28 September 2009]

[23] Sun Microsystems. 2009. *Java Platform Micro Edition Software Development Kit 3.0.* [Online] Available at: http://java.sun.com/javame/downloads/sdk30.jsp [Accessed 28 September 2009]

[24] Sun Microsystems. 2009. *Netbeans 6.8 Download.* [Online] Available at: http://netbeans.org/downloads/ [Accessed 28 September 2009]

[25] Sustrans. 2009. *Bike It.* [Online] Available at: http://www.sustrans.org.uk/what-we-do/bike-it [Accessed 26 September 2009]

[26] Veness, C. (n.d.). *Movable Type Scripts, Calculate distance, bearing and more between Latitude/Longitude points.* [Online] (Updated January 2010) Available at: http://www.movable-type.co.uk/scripts/latlong.html [Accessed 9 January 2010]

[27] Visual Paradigm. 2010. *Streamlined Design and Development Environment (SDE) for NetBeans 5.2.* [Online] Available at: http://www.visual-paradigm.com/product/sde/nb/ [Accessed 12 February 2010]

[28] Mantell J, Rod J, Kage Y, Delmotte F and Leu J. NAVINKO: Audio Augmented Reality-Enabled Social Navigation for City Cyclists, Proceedings of Pervasive 2010,

[29] Jeon M, Park J, Heo U, & Yun J. Enhanced Turning Point Displays Facilitate Drivers' Interaction with Navigation Devices, Proceedings of the First International Conference on Automotive User Interfaces and Interactive Vehicular Applications, (AutomotiveUI 2009), Sep 21-22 2009, Essen, Germany

[30] Härmä, A.; Jakka, J. Augmented Reality Audio for Mobile and Wearable Appliances, JAES Volume 52 Issue 6 pp. 618-639; June 2004.