Towards a new approach to design sounds in public transport

Gaëtan Parseihian[1], Emmanuelle Delgrange[2], Christophe Bourdin[3], Vincent Bréjard[4], Damien Arpaja[2], François Agier[2], and Richard Kronland-Martinet[1] *

[1] LMA, CNRS, UPR 7051, Aix-Marseille Univ, Centrale Marseille, F-13453 Marseille Cedex 13, France
[2] Régie des Transport de Marseille (R.T.M.), Marseille, France
[3] Aix Marseille Univ, CNRS, ISM UMR 7287, Marseille, France
[4] Aix Marseille Univ, LPCLS, E.A. 3278, Aix-en-Provence, France
parseihian@lma.cnrs-mrs.fr

Abstract. This paper presents a collaborative project between the Marseille transit operator and several laboratories from Aix-Marseille University to improve the bus trip with auditory information. A high quality multi channel sound spatialization system was integrated in the bus and a sonification software based on geolocation was designed in order to study three fundamental actions of the sound on bus passengers: designing sound announcement to inform passengers of the next stop in a playful and intuitive way, brightening up the route with spatialized soundscapes to increase the trips pleasantness, and using sound to alert passengers of emergency braking. First, the overall concepts of this project are presented, then the integration of the sound spatialization system and the implementation of the sonification software are described. Finally, evaluation method of passengers satisfaction is discussed.

Keywords: Sound design, sonification, mobility

1 Introduction

"Imagine yourself in a bus in an unfamiliar city. You leave the central station to reach the football stadium. Aggressive city soundscapes fade out as the doors are closing, uncovering an astonishing sound environment. At some stops, the sound of breaking waves comes brushing your ears then return to the front of the bus. Between the bus stops you imagine you can hear seagulls flying in the bus, a soft breeze brushing past your shoulder, and some boat masts knocking together far from you. A passenger informs you of the beaches' proximity and tells you that these are regularly heard in the bus. You continue your travel toward the stadium. While approaching, you hear a growing murmur, this doesn't seem to be due to the good atmosphere in the bus. Some sounds of soccer balls, of whistles, of roaring crowds, etc. The closer you are to the stadium, the more you have the

* This work was funded by the RTM and by Carnot Star.

impression of already being in the stadium. A "ola" wave is heard, coming from the front of the bus, reaching the back then returning back to the front of the bus, some passengers participate. It is followed by the stop announcement "Velodrom Stadium". This time you are sure that you have reached your destination."

This scenario fully illustrates Marseille transit operator (Régie des Transports Maseillais, RTM) vision of next generation of Marseille's buses. More than a way of transport, the bus can become a social and cultural meeting place. Sound ambiances and announcements can suggest places, open the bus onto the city, diminish the stress and transform a simple trip into a tourist and historic stroll, whereas sound alerts can increase passengers' security and prevent numerous accidents; all this in order to offer to the passengers a more pleasant trip. Indeed, nowadays, despite an increasing development of public transport in big cities, the use of personal cars is still dominant inducing many traffic-jams and is an important factor of air pollution. If the first reason is the lack of appropriate line and the difficulty of developing an homogeneous transport network, another frequent reproach to public transport is the lack of pleasantness of the trip. In the bus case, for example, the traffic-jams, the number of passengers or the temperature can transform a simple trip into a real ordeal.

The aim of this article is to present a collaborative project between the Marseille transit operator and several laboratories from Aix-Marseille University to further improve the bus trip using auditory information.

Sound could acts on humans in different ways: it informs [11,4], guides [12], but also influences the behaviour [7]. Considering these interactions, many potential applications might be developed in public transport sector. The sound can inform on the location of particular places, on points of interest along the route, or on the engine dynamic in the electric or hybrid vehicle cases. It can also be used to carry out a specific task (guide the passengers to the rear of the bus) and even influence passengers' behaviour, in term of mood (relaxation) and of posture (anticipatory postural adjustments), especially with the use of immersive sound methods.

The presented project consists in the study of three fundamental actions of the sound on the bus' passengers:

- Alert the passengers of the next stop in a playful and intuitive way: the goal here is to reconsider the sound alerts informing about the bus stops while illustrating those with typical auditory icons inspired from the places and the city history and geography.
- Brighten up the route with spatialized soundscapes to increase the trip's agreeableness: the goal here is to virtually open the bus on surrounding space by generating spatialized and progressive natural soundscapes (sounds of cresting wave, distant boats, seagulls, etc.) in order to positively impact passengers' behaviour and mood while informing them of potential points of interest along the route.
- Using sound to alert passengers of possibly destabilizing emergency braking: the goal here is to use spatialized and dynamic sounds in order to alert, in

advance, the passengers (particularly those who stand up) of destabilizing emergency braking to avoid falls.

For this purpose, a high quality multi-channel sound spatialization system composed of ten loudspeakers was integrated in the bus and a sonification software based on geolocation was designed.

This article describes the different aspects of this project. First, the three fundamental actions of the sound on the passengers are succinctly described. Then, the integration of the sound spatialization system in the bus and the implementation of the sonification software are detailed. Finally, first works on the evaluation of the device by passengers are discussed.

2 Project overview

2.1 Playful and intuitive stop announcement

Auditory warnings in public transports Clear and consistent on-board stop announcements are vital to ensure that buses are accessible to and usable by people with disabilities, as well as by visitors or others who may not be familiar with the service area. Without adequate on-board stop announcements some riders may have difficulty knowing when to get off the vehicle.

Traditionally, stop announcements are made manually by vehicle operators using a public address system or provided as part of an automated voice announcement system [2]. For automated voice announcement, vehicle operator can choose between using a text to speech software or pre-recorded voice. In both cases, the message must be clear and not misunderstood.

During the last few years, in addition to the vocal announcement, some vehicle operators have added different types of sounds to the stop announcement in order to increase its attractiveness and to distinguish their company from the others. For example, Paris' and Strasbourg' tramway stop announcements were designed by the sound artist Rodolphe Burger. They are made of musical jingles and voices. For each stop, a particular musical jingle and a pair of voices were recorded to design two different stop announcements for each stop (an interrogative announcement and an affirmative announcement). Evocative, playing with our musical memory, the musical jingles are inspired by the names of the stops and allow to introduce the voice announcement. For another example, the composer Michel Redolfi has introduced the concept of "sonal" for the tramways of Nice, Brest, and Besançon. Unlike the jingles (which suggest unchanging and monotonous stop announcement that sounds like a warning), the sonals are designed as musical sounds that can change over time. According to their designer, they discretely accompanies the riders on their journey and contains musical, vocal and historic elements linked to the specific features of the places and to the unconscious collective sounds shared by the local population. In Nice, the sonals vary randomly at each stop with a different night and day version. Some of the announcements are dubbed in the Nice dialect (Nissarte). In Brest, the designers wanted to evoke, without exaggerating, the marine context. The sonals are pronounced by a women when the tide is coming in and a man as the tide is going out. Of course, the time of the day when it shifts is different everyday, but this design allows passengers to know where the sea is. As for Nice's tramway, the announcements are randomly dubbed in the local Breton dialect.

Our approach For this project, our intention is to design spatialized intuitive and playful auditory announcements (coupled with the traditional vocal announcement) having a semantic link with the bus stop. Hence, we want to rethink the sounds related to the bus stops by illustrating its with typical auditory icons of the places and of the city. For example, before arriving to the soccer stadium bus stop, a wave will be joined to the traditional announcement voice in order to notify to the passenger the stadium proximity. While the definition of typical sounds which can be easily identifiable and recognized by all the passengers is simple for few bus stops, the process of finding evocative sounds for all the stop is difficult or impossible. Thus, rather than looking for immediate correspondences between stops' names and sounds, our approach is to draw inspiration from the identity, the specificity and the history of the places crossed by the bus. In this way, a bike sound at Michelet Ganay stop can inform us that Gustave Ganay was one of the most famous cyclists from the 1920s and that he was native from Marseille. The sound of stream waters at Luminy Vaufrèges stop informs about the presence of an underground river. An extract of Iannis Xenakis music at Corbusier stop allows the passengers to discover the close links between music and architecture, etc. Linked to a dedicated website or application (detailing and adding supplementary informations about the sounds used for each stop), these auditory icons tend to transform an ordinary trip from one place to another in a historic, tourist, and heritage visit.

With the spatialization of sound, auditory icons travel in the bus following the wave metaphor, giving the sensation of a sound that informs the passengers one by one, starting from the front of the bus and propagating to the back of the bus. In addition to the playful aspect, the use of the sound spatialization allows to attract the passengers attention by opposition to the usual announcement immobility. Different types of waves will be studied as a function of the auditory icon types. Indeed, the simple propagation from the front to back is of interest for some auditory icons while other will be easily perceived with a round trip trajectory or with a circular trajectory (e.g. starting from the right side of the bus and returning by the left side).

For a correct identification of the stop name by all the passengers, auditory icons are coupled with traditional voice clearly announcing the stop name. This vocal announcement is uniformly played on all the ten loudspeakers to ensure the most homogeneous diffusion in the bus and to guarantee the best hearing comfort and optimized intelligibility for all the passengers and in all the situations.

By convention, in the bus, a stop is announced twice: the first occur around 100 meters after the previous bus stop, the second takes place around 30 meters before reaching the stop. Depending on the transport company's or sound designer's choice, these two types of announcement are differentiated by the voice prosody or by the way they are introduced (using "next stop is..." or "stop:..." for example). This differentiation with auditory icons is based on the sound duration. First type of announces are associated to a long auditory icons (a sound between 5 and 10 seconds) while second type are associated to short auditory icons (between 1 and 2 seconds).

Finally, in order not to disturb and bother regular users, only a selection of few stops will be sonified to punctuate the trip. Selected stop and corresponding auditory icons can change according to the time (morning, afternoon, week-end), and to the traffic (peak or off-peak periods).

2.2 Designing soundscapes for trip's enhancement

Closed environment, high temperature during summer, direct contact with other passengers during peak periods, traffic jams, etc. In certain situations, a bus trip can become highly stressful for the passengers who are forced to undergo their uncontrollable environment and the foreign discomfort [8]. To reduce these problems, the idea here consists in enhancing the trip with spatialized soundscapes in order to virtually open the bus toward the surrounding space and to increase trip's agreeableness.

Effect of environmental sounds on stress Several studies have demonstrated restorative effects of natural compared with urban environments; these effects include increased well-being, decreased negative affects and decreased physiological stress responses [16,17,9]. In [17], Ulrich suggested that natural environments have restorative effects by inducing positive emotional states, decreased physiological activity and sustained attention. Considering the influence of natural sounds, a study by Alvarsson et al. [1] suggests that, after psychological stress, physiological recovery of sympathetic activation is faster during exposure to pleasant nature sounds than to less pleasant noise of lower, similar, or higher sound pressure level. Benfield et al. [3] highlight a better relaxation with natural sounds compared to no sound or to natural sounds mixed with human sounds (voice or motor). Watts et al. [18] describe the beneficial effects on anxiety and agitation of introducing natural sounds and large images of natural landscapes into a waiting room in a student health center. Other studies highlight the positive impact of music on stress reduction. In [6], the authors suggest that listening to certain types of music (such as classical) may serve to improve cardiovascular recovery from stress.

Our approach of soundscapes design for the bus In order to reduce passengers anxiety and to virtually open the bus, the project aims at enlivening the bus trip with:

- Spatialized contextualized natural soundscapes (composed with typical sounds from Marseille and its surrounding) and musical ambiances;
- Point Of Interest (POI) sound announcements (museum, monuments, parks, beaches, etc.)

Soundscapes and POI are geolocalized and triggered when the bus passes close to their position on the route. For the POI, as in augmented reality, the sounds are virtually placed on the object they are representing, that is the POI sound appears to come from the POI position. Hence, when passing by a church, the passengers will feel that the tinkling of the bells come from the church (the sound spatialization is based on the POI position with respect to the bus). The soundscapes are constructed to reflect a particular atmosphere or universe in coherence with the route or the neighbourhood, to give an overview of typical sounds surrounding the city, or to offer a trip based on musical ambiances. For example, in a city close to the sea, soundscapes might be composed of sea sounds (waves, boats, wind, seagull, etc.), and in highly urbanised area forests' sounds can be recommended. In addition to stress reduction, designed soundscapes will allow to divide the bus itinerary in several parts according to crossed neighbourhood and places.

Soundscapes design is based on a random reading of the preselected sound samples in order to avoid redundancy that could annoy and tire regular passengers. With this process, on one part of the route, soundscape ambiance is always the same but the sound events doesn't appear twice at the same time and at the same position. Sounds trajectory and frequency of appearance may vary as a function of the time of the day but also as a function of the traffic, the temperature, or the passengers number. It is also possible to design several similar soundscapes and to associate them to different periods of the week (morning or afternoon, week or week-end, for example).

2.3 Using sounds to secure the passengers

The third part of the project aims at studying brief spatialized warning sounds designed to prevent bus passengers from emergency braking. The idea is to use dynamic and spatialized sounds in order to alert, in advance, the passengers (particularly those who stand up) of destabilizing emergency braking. In the bus, some of the passengers do not stand up in the same direction as the bus circulation and do not necessarily see the road. This results in an impossibility of predicting sudden vehicle movements and in an important postural destabilisation. Our objective is to analyse driver's foot behaviour to predict braking phases and produce an auditory warning allowing the subject to produce anticipatory postural adjustment.

High postural perturbations, such as those induced by emergency braking, endanger the body's stability. In order to preserve the equilibrium, as a function of the perturbation's predictability, humans can produce compensatory postural adjustment (CPA) and/or anticipatory postural adjustment (APA). In [13,14], the authors highlight the importance of APAs in control of posture and points out the existence of a relationship between the anticipatory and the compensatory components of postural control. It also suggests a possibility to enhance balance control by improving the APAs responses during external perturbations. In a study by [10] et al., the authors show that auditory precuing can play a role in modulating the automatic postural response. They demonstrate that a general warning signal, evoking alertness, can reduce automatic postural response latency but fail to give information about the perturbation direction with the auditory signal content [10].

For this part of the project, we are currently exploring the role of sound spatialization and of sound content as directionally specific pre-cue information for the execution of anticipatory postural adjustments and the reduction of automatic postural response latencies. This experiment will take place in laboratory rather than in a bus with an experimental setup composed of a force-controlled waist-pull perturbations system [15], three loudspeakers for spatial sound generation, a force platform for the measure of postural adjustments, and a PhaseSpace motion capture system for the analysis of protective stepping. To properly reproduce the perturbation, bus deceleration during emergency braking was measured with an accelerometer in a bus braking from 50 to $0 km.h^{-1}$. Several measurements were done. Mean decelerations duration during the braking was $1.37 \pm 0.37s$ with a mean deceleration of $0.77 \pm 0.04g$.

If the results of this experiment are conclusive, the advantage of sounds to accelerate automatic postural responses will be studied in real environment in the bus on a parking and finally the system efficiency will be evaluated with the statistics on passengers accidents.

3 Functional overview

3.1 Integration of a high fidelity multichannel sound spatialization system in the bus

One of the most innovative part of this project corresponds to the use of spatial sounds in the bus. Indeed, if bus and more generally public transports are equipped with several loudspeakers, the same acoustic signal is always emitted by all the loudspeakers. Here the three parts of the project are based on the use of spatial sounds and thus on the emission of different sounds by different loudspeakers. The integration of the high fidelity multichannel sound spatialization system is fully described in this section.

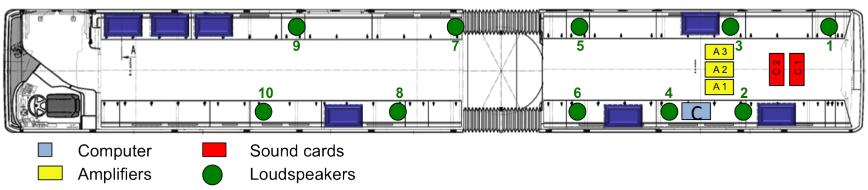

Fig. 1. Diagram of the integration of the different parts of the multichannel sound spatialization system in the bus.

This system is composed of:

– 10 loudspeakers
– 3 amplifiers (4 channels)
– 2 soundcards
– 1 computer Mac Mini

The placement of each device is detailed on the diagram of figure 1.

For the first prototype, the system was set up in a hybrid articulated bus (CITARO G BlueTec Hybrid from Mercedes-Benz) which will serve the line 21 of Marseille's transport network. The ten loudspeakers were installed on the overhead panel (cf figure 2). Four loudspeakers were distributed at the back of the front part of the bus and six loudspeakers were distributed at the rear part of the bus. This distribution was chosen to ensure a sound diffusion as uniform as possible with spatialization fluidity while preserving half of the front part of the bus and the driver from the sound. The three loudspeakers and the two sound cards were installed on the ceiling's metallic frame, the computer was set up with silent block in an overhead panel. Amplifiers are supplied via traditional bus circuit in 24 Volt, computer is supplied with a specific socket in 220 Volt.

Fig. 2. Fixation of the amplifiers (top left), the sound cards (top right), and the loudspeakers (bottom).

3.2 Software overview

The different objectives of the project will be attained by combining input data furnished by the bus system and geo-referenced data extracted from a geographic information system (GIS). Bus sonification will be provided using spatialized audio rendering with pre-recorded voice, auditory icons and soundscape. We built an innovative system prototype with an architecture divided into several functional elements. The general architecture of the system is shown in figure 3. Each part of the system is described below.

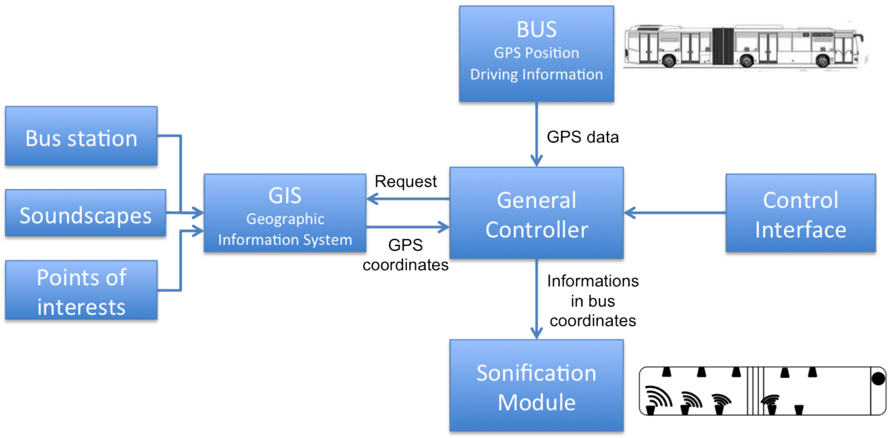

Fig. 3. General architecture of the system.

Geographic Information System Geographic Information System (GIS) stocks, manages and returns the geographic data useful for the sonification. In actual prototype, three types of geographic informations are necessary (see section 2): bus stop positions, points of interest and soundscapes positions.

The positions of the bus stops that characterize the path are extracted from the RTM database. For each bus line, two separates paths (outward and return) are created and exported to GoogleEarth via kml files. For each bus stop the stop name is associated to the stop position (illustrated by yellow drawing pins on figure 4).

POI and Soundscapes data are created and positioned with GoogleEarth. For each position, tags are set for the object type (POI or Soundscape), the object name, and the range (in meter). With these informations, the General Controller decides, as a function of the bus position in the path which information is to be sonified and how. POI and Soundscapes are represented with red and green drawing pins on figure 4, their ranges are represented with plain circles.

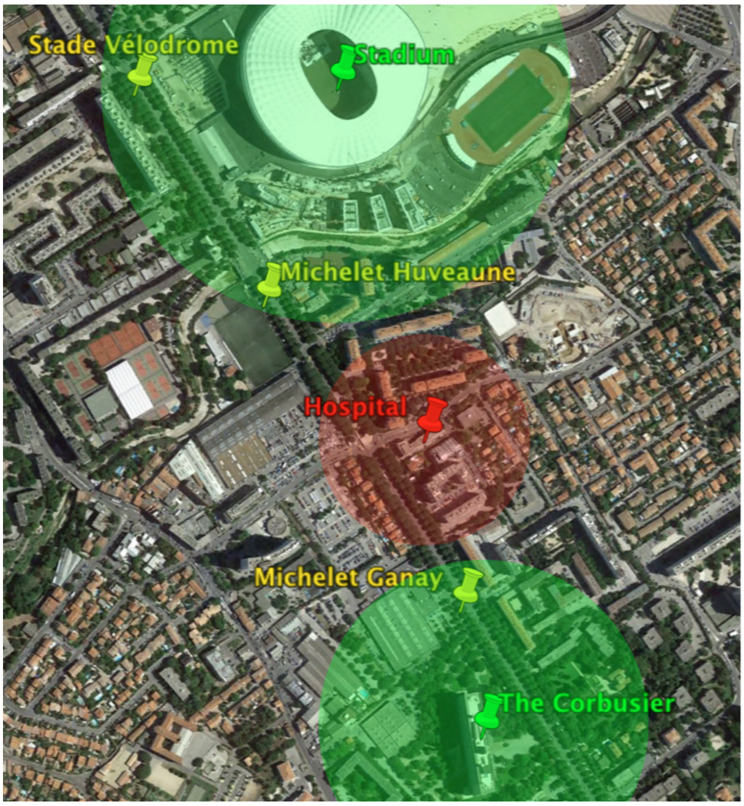

Fig. 4. Screen capture of GoogleEarth representing a part of line 21 bus path. Drawing pins represents GIS informations with bus stops in yellow, POI in red, and Soundscape in green. Red and green plain circles represent the ranges of each POI and Soundscape.

Informations from the bus Several informations need to be transmitted in real time from the bus to the General Controller for proper functioning of the system. First, at the beginning of the trip, the number of the bus line and the driving direction (outward or return) are sent to the General Controller for the selection of the appropriate GIS informations. During the trip, GPS bus position is sent each second to the General Controller for the trajectory following and the sounds triggering. Driving informations required to detect emergency braking are currently under review. The first approach consists in the analysis of the brake pedal state, but a detection system only focused on this information might be too slow to permit an appropriate anticipatory reaction from the passengers. To tackle this problem, we are analysing feet movements with respect to acceleration and braking pedals states and inertial unit in order to detect emergency braking at least 200 ms before the deceleration. When available, these informations are taken from the Controller Area Network.

Control Interface The user interface allows the access to the sonification device setting. In normal conditions, the device works independently from any human intervention as a closed on-board system. In order to set-up the appropriate sounds, to adjust the levels of the different sound information (voice, stop sounds, soundscapes, and POI sounds), and to define the sound triggering laws (date and time slots of functioning), a user interface was created. It allows to remotely connect to the device computer and to adjust the settings with a WIFI connection.

General Controller Central core of the system, the General Controller collects data from the GIS, the bus and the Control Interface to determine, during navigation, what notification messages are to be presented to the user. All the geolocalised data are converted into Cartesian coordinates and objects positions are calculated as a function of the bus position (for each new bus coordinate). Depending on the objects' distance and the settings, the central core identifies the informations to sonify and send the appropriate messages to the sonification module.

Sonification Module Developed with Max/MSP software, the sonification interface manages the sounds triggering and the spatialization. It consists in three modules for the control of the stop announcement, the soundscapes management, and the braking alert triggering. Each modules are constructed to run in real time as a function of bus position and informations.

4 Passenger evaluation of the system

Designing such a project without taking into account the passenger and the driver general satisfaction will be useless. Indeed, the sound design for the bus is dedicated to the bus passengers who can be tourists, occasional or regular users.

Evaluation campaigns are planned in order to evaluate the user satisfaction, to measure the stress reduction due to the use of natural soundscapes, the proper understanding of the auditory icons, and the intelligibility of the sounds. As bus passengers may not be available for a long time (the mean trip duration in the bus is around fifteen minutes), it is important to design a short evaluation procedure. A survey of five questions has been designed and is under evaluation in laboratory to evaluate its efficiency with a correlation to traditional stress measurement methods (physiological measures such as skin conductance level and heart rate variability). This survey is based on visual analogue scale for stress and anxiety, and items assessing valence and intensity of emotional state (Self Assessment Manikin [5]) on the other hand. After the laboratory validation of this survey, the bus sounds will be evaluated during the trip by measuring the evolution of passengers' emotional state between the beginning and the end of the trip.

5 Conclusion

This paper introduces a collaborative project that aims at improving bus trip with auditory information. Thanks to the design of a high quality multi-channel sound spatialization system and the implementation of a sonification software based on geolocation, three fundamental actions of the sound on the bus passengers will be studied. We believe that the use of playful stop sounds announcement paired with spatialized natural soundscapes can de-stress the bus passengers and transforms a simple trip into a tourist and historic stroll. Furthermore, the use of sound to alert passengers of possibly destabilizing emergency braking can prevent of passengers accidents. Taken together, the three aspects of this project constitute a new approach for the design of sounds for public transport that may increase people's interest for the use of public transport. With such systems, it is also simple to transform a bus trip into a musical composition based on geolocation that could bring sound art to a new public.

References

1. J. J. Alvarsson, S. Wiens, and M. E. Nilsson. Stress recovery during exposure to nature sound and environmental noise. *International journal of environmental research and public health*, 7(3):1036–1046, 2010.
2. P. Barthe. Announcing method and apparatus, June 3 1958. US Patent 2,837,606.
3. J. A. Benfield, B. D. Taff, P. Newman, and J. Smyth. Natural sound facilitates mood recovery. *Ecopsychology*, 6(3):183–188, 2014.
4. M. Bezat, R. Kronland-Martinet, V. Roussarie, and S. Ystad. From acoustic descriptors to evoked quality of car-door sounds. *Journal of the Acoustical Society of America*, 136(1):226–241, 2014.
5. M. M. Bradley and P. J. Lang. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry*, 25(1):49–59, 1994.

6. S. Chafin, M. Roy, W. Gerin, and N. Christenfeld. Music can facilitate blood pressure recovery from stress. *British journal of health psychology*, 9(3):393–403, 2004.
7. L. Gandemer, G. Parseihian, R. Kronland-Martinet, and C. Bourdin. The influence of horizontally rotating sound on standing balance. *Experimental brain research*, 232(12):3813–3820, 2014.
8. B. Gatersleben and D. Uzzell. Affective appraisals of the daily commute comparing perceptions of drivers, cyclists, walkers, and users of public transport. *Environment and behavior*, 39(3):416–431, 2007.
9. B. Grinde and G. G. Patil. Biophilia: does visual contact with nature impact on health and well-being? *International journal of environmental research and public health*, 6(9):2332–2343, 2009.
10. J. McChesney, H. Sveistrup, and M. Woollacott. Influence of auditory precuing on automatic postural responses. *Experimental brain research*, 108(2):315–320, 1996.
11. A. Merer, M. Aramaki, S. Ystad, and R. Kronland-Martinet. Perceptual characterization of motion evoked by sounds for synthesis control purposes. *Transactions on Applied Perception*, 10(1):1–24, 2013.
12. G. Parseihian, C. Gondre, M. Aramaki, S. Ystad, and R. Kronland-Martinet. Comparison and evaluation of sonification strategies for guidance tasks. *IEEE Transaction on Multimedia*, 18(4):674–686, 2016.
13. M. J. Santos, N. Kanekar, and A. S. Aruin. The role of anticipatory postural adjustments in compensatory control of posture: 1. electromyographic analysis. *Journal of Electromyography and Kinesiology*, 20(3):388–397, 2010.
14. M. J. Santos, N. Kanekar, and A. S. Aruin. The role of anticipatory postural adjustments in compensatory control of posture: 2. biomechanical analysis. *Journal of Electromyography and Kinesiology*, 20(3):398–405, 2010.
15. D. L. Sturnieks, J. Menant, K. Delbaere, J. Vanrenterghem, M. W. Rogers, R. C. Fitzpatrick, and S. R. Lord. Force-controlled balance perturbations associated with falls in older people: a prospective cohort study. *PloS one*, 8(8):e70981, 2013.
16. R. Ulrich. View through a window may influence recovery. *Science*, 224(4647):224–225, 1984.
17. R. S. Ulrich, R. F. Simons, B. D. Losito, E. Fiorito, M. A. Miles, and M. Zelson. Stress recovery during exposure to natural and urban environments. *Journal of environmental psychology*, 11(3):201–230, 1991.
18. G. Watts, A. Khan, and R. Pheasant. Influence of soundscape and interior design on anxiety and perceived tranquillity of patients in a healthcare setting. *Applied Acoustics*, 104:135–141, 2016.