SONIFYING THE PERIPHERY: SUPPORTING THE FORMATION OF GESTALT IN AIR TRAFFIC CONTROL

Niklas Rönnberg
Division for Media and Information Technology
Linköping University
Norrköping, Sweden
niklas.ronnberg@liu.se

Jonas Lundberg
Division for Media and Information Technology
Linköping University
Norrköping, Sweden
jonas.lundberg@liu.se

Jonas Löwgren
Division for Media and Information Technology
Linköping University
Norrköping, Sweden
jonas.lowgren@liu.se

ABSTRACT

We report a design-led exploration of sonification to provide peripheral awareness in air traffic control centers. Our assumption is that by using musical sounds for sonification of peripheral events, it is possible to create a dynamic soundscape that complements the visual information to support the formation and maintenance of an airspace Gestalt throughout the air traffic controller's interaction. An interactive sonification concept was designed, focusing on one controlled sector of airspace with inbound and outbound aircraft. A formative assessment of the sonification concept suggests that our approach might facilitate the air traffic controller's work by providing complementary auditory information about inbound and outbound aircraft, particularly in situations where the traffic volume is moderate to low.

1. INTRODUCTION

Each air traffic controller manages the flow of aircraft of a designated airspace, a sector (see Figure 1), focusing on aircraft moving within the sector as well as inbound and outbound traffic. Other sectors can be on all sides, including above and below. The primary information channel is the visual modality, and the air traffic controller's work is focused on the primary flight display (the "radar screen"), with additional information given on adjacent displays [14]. Their most safety-critical task is to detect potential situations where aircraft may get too close to each other. Two main strategies are available, the first being to scan the sector visually, inspect the status of each aircraft and optionally display its flight path. The second strategy involves using a "time to conflict/distance between aircraft" scatter plot to predict conflicts and then inspect concerned aircraft and flight paths in a more focused manner [12, 13, 14]. In both cases, focal attention on visual objects interplay with looking for specific situations and with building and maintaining general awareness. This notion of general situational awareness is a key element in air traffic control, manifested for instance in handoff sequences where an air traffic controller about to leave a shift waits for the relieving controller to declare that he/she has grasped "the big picture" of the current airspace situation before actually passing on formal control. The concept of Gestalt is quite common in

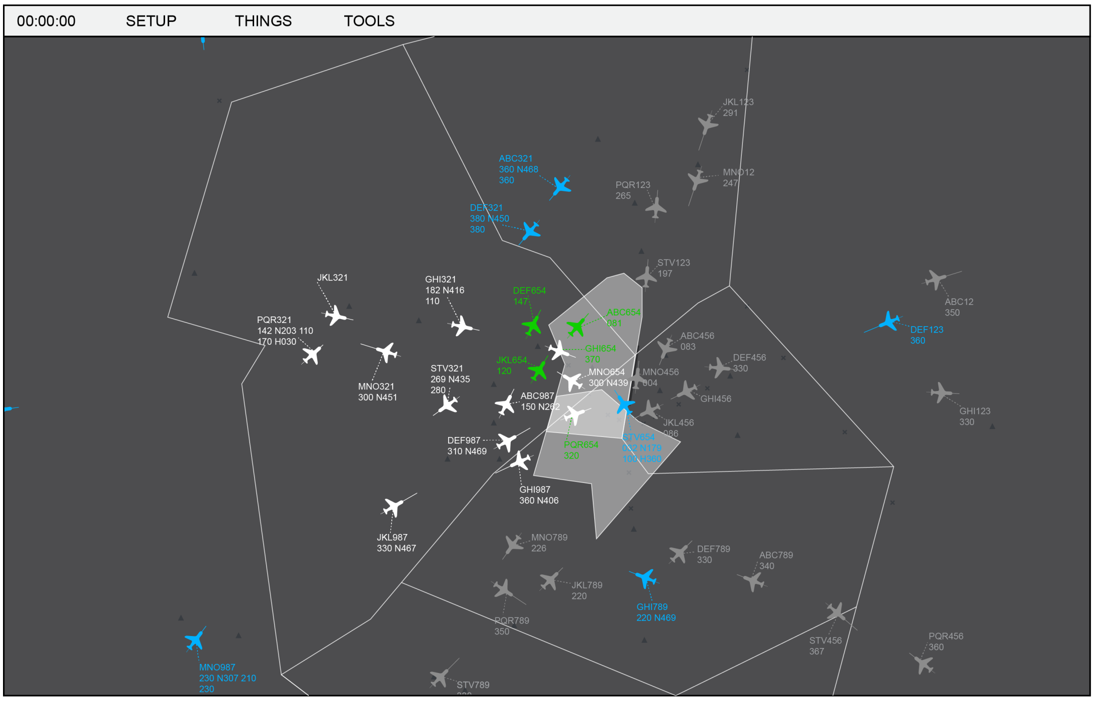

Figure 1. *Anonymized rendering of a radar screen showing an airspace sector, modified by the authors for confidentiality reasons. In this illustration, white aircraft are under the control of the air traffic controller for the sector. White aircraft with green text are outbound aircraft that have not yet been taken over by the next air traffic control sector. Green air crafts are outbound aircraft under control of another sector. Light grey aircraft are not inbound to the sector, and light blue aircraft are inbound to the sector.*

design as well as psychology, referring to a holistic sense of an overall composition that goes beyond a simple sum of the constituent parts, and we find it to be an apt metaphor for the air traffic controllers' "big picture". It is built from focal information (aircraft currently in the controlled sector) as well as peripheral (aircraft about to enter and leave the sector) and as we shall see below, the current tools for visual presentation and navigation of this information are not ideal for forming and maintaining the Gestalt of the airspace situation in its entirety.

Aircraft are represented on the radar screen as symbols, usually squares with trailing dots indicating e.g. air speed, of airplanes, colour coded to indicate priority and with associated text information (see Figure 1). In the system used for this study, airplanes inbound to the airspace sector have one colour, while outbound airplanes have another colour. Adjacent displays provide similar information in the form of text lists. The primary modality for the air traffic controller is consequently the visual, and the demands are high on the ability to quickly and systematically shift the focus of visual attention between aircraft in and near the sector, to continually rebuild awareness and the Gestalt of the current situation.

Bromma airport is located south of Stockholm, Sweden. The airspace sector around Bromma is controlled by the air traffic control center located near Arlanda airport north of Stockholm. This airspace sector has aircraft inbound to and outbound from Bromma airport, passing aircraft inbound to and outbound from Arlanda airport, as well as passing aircraft in all directions. At certain times during a day there are several aircraft inbound for Bromma within a short period of time. Some of these aircraft come from the south of Sweden, some from the north, some are inbound from Finland in the east, some are inbound from Norway in the west, and finally some are inbound from Denmark in the south west. In addition to this there is air traffic passing through the sector. In order to plan flight routes, the air traffic controller constantly has to move the center-point of the radar screen and zoom in or out while trying to grasp and keep in mind the speed, distance, and route of all inbound, outbound, and passing aircraft. In order to maintain good control of the airspace sector, when the load on the controller gets too high, the sector is usually divided into one outer sector and one inner sector that is closer to Bromma airport, and thus the airspace sector is controlled by two air traffic controllers.

Air traffic controllers need a grasp of the Gestalt of the airspace – the big picture, a sense of an organic and dynamically shifting whole – in order to do their work properly. The tools currently at their disposal, with much required overhead in terms of zooming and center-point-shifting and with an exclusive orientation to the visual modality, do not entirely support the formation and maintenance of a workable airspace Gestalt. This is the starting point for the work reported here.

The visual information could be supplemented with auditory information to better support the airspace Gestalt formation and maintenance. The aural modality might be described as another set of eyes and ears [16], and would consequently provide a benefit for the air traffic controller. In spite of this, auditory presentation is rather underexploited in today's air traffic control environment. Continued digitalization of the whole system is expected to reduce the use of voice to communicate and coordinate even more. Sounds in the current interface are used as warnings or alerts, but they do not contribute holistically to the big picture of the airspace. The existing interface sounds are more often perceived as distracting and annoying than as meaningful and connotative, and sometimes the air traffic controller even mutes them.

We postulate that it is possible to use musical sounds to create a soundscape that sonifies peripheral events and thereby complements the visual information to support the formation and maintenance of an airspace Gestalt. As stated previously in this paper, the main drawback of current tools is that they require extensive manipulation, for the air traffic controller to collect all the information needed to build and maintain a Gestalt sense of the airspace. This disrupts the flow of the work. The notion of "all the information" entails focal information (aircraft currently in the sector for which the air traffic controller is responsible) as well as peripheral (aircraft inbound the sector and aircraft about to leave the sector). Our approach is to complement existing visual presentations and tools with aural information, i.e. the sonification, thus forming a multimodal information presentation hopefully better suited for building and maintaining the Gestalt. The overall concept is to keep the focal information visual and to sonify the peripheral information. We expect this approach to enable maintained concentration on focal tasks but with increased peripheral awareness. Ideally, this would also lead to less cognitive load in the visual modality.

2. SKETCHING SONIFICATION FOR AIR TRAFFIC CONTROL

Any sonification must coexist with radio calls to and from aircraft, as well as internal communication within the air traffic control center. Therefore, the sonification must be designed to be transparent and ambient, informing about peripheral events without being disruptive [8], in order to avoid competition with existing sounds. Our interest lies therefore within sonification as a complementary modality [15]. Furthermore, the sonification must be designed to provide auditory information without taxing the cognitive system of attention, but allowing the air traffic controller to maintain concentration on the visual tasks.

In order for a sonification to be perceived and experienced, creating a meaningful soundscape of peripheral events, without requiring additional cognitive resources to be allocated, the sonification should be heard but not listened to. Hearing can be regarded as a mainly passive function that provides access to the auditory world via perception of sounds. Listening can then be viewed as a higher order function that requires intention and attention [11] which in turn draws on cognitive resources. A successful sonification for an air traffic control center should be experienced holistically and peripherally, and consequently the meaning in the sonification should come out of hearing it rather than attentively listening to it.

The design process was initiated with an informal observational study of an air traffic control center. This gave valuable insights into the air traffic controller's work, the air traffic control tools, and the air traffic control center environment. The primary outcome of this observational study was in identifying situations where the air traffic controller had to change focus, zoom in or out, or move the center-point of the radar screen in an attempt to get a sufficient overview of the airspace (see Figure 1). These situations were specifically found while identifying inbound aircraft that had not yet appeared on the default presentation setting on the radar screen. Another situation that seemed to pose a heavy load on the visual modality was in keeping track of outbound aircraft that had been handed over by the air traffic controller but not yet accepted by the controller of the next sector.

Next, an interactive sonification concept was sketched by sonifying a 30-minute video recording of a radar screen, focusing on 1) aircraft inbound to the controlled sector and 2) aircraft outbound of the controlled sector (see blue inbound aircraft and white outbound aircraft with green text in Figure 1). The concept entailed the following three principles for the air traffic controller's interaction with the envisioned system. First, as soon as the control of an inbound aircraft was transferred to the air traffic controller of the controlled sector, the sonification of the aircraft stopped. Second, the sonification of the aircraft outbound of the sector was stopped as soon as the control of the aircraft was accepted by the air traffic controller of the next sector. This created something of an aural periphery, sonifying aircraft that were of interest for the air traffic controller but not in the current focus of attention. Finally, aircraft that were at the center of the air traffic controller's attention were not sonified. Consequently, the air traffic controller does not interact with the sonification per se, but rather uses the sonification as a part of the air traffic control system. The airspace is sonified through actions and interactions of the air traffic controller and air traffic controllers in adjacent sectors, and reflects processes within the airspace. As air traffic controllers (e.g. including actions of air traffic controllers in adjacent sectors) interact with the traffic, they also interact with the sonification.

The sounds used in the sonification sketch were massed synth strings, played softly with the high-frequency content somewhat attenuated. The attack of the sound was accented with a soft electronic piano sound. Even though some research suggests that natural real-world sounds might be better in a soundscape for monitoring and control [3, 9, 10], we chose to use musical sounds. There are several reasons for this. Most significantly, musical sounds when combined together create an emergent musical timbre that make small and large volumes of aircraft distinguishable. Furthermore, musical sounds create a changing soundscape, which in turn brings meaning and significance without becoming constant and repetitive. Therefore, a musical approach has potential to work as an emergent whole, supporting the formation of a Gestalt and hence appropriate awareness of the entire airspace. The first among the possible alternatives to musical sonification would be to use the existing interface sounds. However, it is easy to conclude that they would not work in concert to support the formation of meaningful wholes, since they were designed as artificial alert signals corresponding to specific events. They are therefore not viable elements of a new soundscape intended to support an understanding of the airspace Gestalt. They do still serve a purpose of sorts and a new soundscape based on musical sounds would complement the existing sounds without conflicting with them. A final alternative is the use of ”natural” aircraft engine sounds, forming auditory icons [5] of aircraft. We find that this alternative suffers from similar shortcomings – it is dubious whether auditory icons in concert would form a soundscape with meaningful holistic characteristics, and the icons themselves could tend to suggest inappropriate connotations of individual aircraft engine operation status rather than mere peripheral presence.

The two musical sounds used in the sketch differed in pitch, but were tuned and in the same tempo. For incoming aircraft, the pitches used were C4, G4, A3, F3, E4, C5, D3, A4 creating rather pleasant harmonies with separable tones [4]. These tones were steady with a slow variation of the overtone frequencies to create a slowly changing soundscape. As new aircraft of interest were discovered by the radar, the tones alternated serially generating changing harmonies and chord patterns. For aircraft leaving the controlled sector, the pitch was one octave higher and in a slow syncopated rhythm. In this design sketch, only eight inbound and outbound aircraft could be sonified at the same time.

The sketch illustrates an attempt to design an interactive sonification that would be conducive to the maintenance of situation awareness, since the emerging composition created by inbound and outbound aircraft exhibit discernible variations in qualities such as harmony and complexity, while at the same time forming a meaningful whole.

The reader is encouraged to listen to a short excerpt of the sonification sketch, to achieve a better understanding of the sonification. Unfortunately, for confidentiality reasons the original video showing air traffic on the radar screen cannot be made available online. The excerpt covers a time period in which a total of nine aircraft are inbound to the controlled sector, and four aircraft are outbound.
http://www.itn.liu.se/~nikro27/ison2016/ison2016_sample.mp3

3. FORMATIVE ASSESSMENT OF THE INTERACTIVE SONIFICATION CONCEPT

The interactive sonification concept described above was assessed in a focus group with three experienced licensed air traffic controllers in collaboration with the Air Navigation Services of Sweden (LFV). A focus group is well suited for a formative evaluation in an early conceptual design phase such as this. The focus group consisted of one woman and two men with a median age of 59 years (range 55 to 61) with a mean operational air traffic controller service of 21.3 years (range 18 to 26), and a mean additional years of work in LFV of 14.6 (range 6 to 20). The participants of the focus group were selected due to their long experience of operational air traffic control service, as this was considered to give better insights into the qualities of sonification in this specific setting. The focus group session was initiated with a thorough description of the interactive sonification concept, followed by a 15-minute demonstration of the sketch.

The participants of the focus group were informed that the primary purpose was to assess the idea of interactive sonification as a concept, and to evaluate if sonification could lead to a better awareness of the airspace as a whole, rather than evaluating the detailed design choices of sounds, tones and intervals used in the sketch. The secondary aim was then to discuss possible proposals, improvements and new complementary ideas to the concept, such as targets for sonification, the patterns of interaction between the sonification and the air traffic controller as well as between the sonification and the existing air-traffic control interface. The participants were free to describe and discuss their impressions of the sonification sketch without any intervention of the moderator. The focus group discussion took approximately 60 minutes. The discussion was recorded and transcribed for subsequent analysis using qualitative induction.

The overall finding from the assessment suggests that sonification may be a valid way to provide information about peripheral inbound aircraft to the air traffic controller, and that this extra information would facilitate the air traffic controller's work. It was also found that using sonification to remind the air traffic controller about outbound aircraft may provide useful information about aircraft that easily could be overlooked or forgotten. On a broad scale, then, the interactive sonification concept introduced here seems to have some potential for supporting air traffic controllers in forming and maintaining the airspace Gestalt. Moreover, it was pointed out that the lack of sonification in completely controlled situations is a benefit, by virtue of creating a dynamic variation between sound and silence, and thus counteracting the risk of perceiving a constant soundscape as stressful or starting to ignore it due to habituation.

However, an equally important finding concerned situations with high amounts of air traffic. In such situations, the need for sonification was considered as less, compared to situations when the air traffic is at medium or low levels. The reason is that during periods of high-volume air traffic, the air traffic controller is prepared and aware of the traffic. Under such conditions, the airspace kept under immediate surveillance is probably diminished, and the time period for planning ahead is most likely shortened as well. The Gestalt of the airspace, even if the airspace is reduced in size, is then created and maintained via extensive work with visual information, requiring high cognitive demands. Under such conditions, it was suggested that a sonification constantly indicating inbound aircraft would not assist the air traffic controller but rather add negatively to the overall input load. It was proposed that the sonification should be muted during high-volume traffic, as the amount of radio calls as well as possible alerts and warnings would be increased. On the other hand, during periods of medium to low air traffic, when the air traffic controller's attention and concentration decreases, sonification could beneficially be used to provide peripheral information as well as reminders about upcoming tasks and events. The interactive sonification concept was therefore considered to provide an interesting extra dimension.

Moreover, it was made clear in the focus group that the air traffic control environment is different in different places. Therefore, the uses and benefits of sonification might differ. The air traffic control environments in Sweden are rather quiet and calm, and sonification was therefore regarded as potentially relevant for most environments in Sweden, such as air traffic control centers, but particularly for tower and multiple remote towers.

Interestingly, the interactive sonification concept as presented in the sketch was not considered to provide a complete Gestalt of the airspace together with the visual information, due to the lack of spatial information provided by the sonification. It was suggested that spatial audio information could be beneficial to the air traffic controller. However, the use of headphones or speakers might be restricted in different air traffic control environments, but it was suggested that such a technique could be useful in multiple remote towers. Spatial audio information provided via headphones, for example, could give implicit support to orient the air traffic controller's attention in the right direction.

Moving on to the details of the proposed sonification and suggested improvements, it was noted that there might be a need to make changes more clearly discernible in the overall soundscape. Changes in dynamics, i.e. changes in amplitude, were discussed as well as differences between the extremes quiet and sound. To illustrate this, an example was suggested of an inbound aircraft that is sonified at a low amplitude when it is far from the control sector, but with increased amplitude as distance decreases. The harmonic content was also mentioned and suggested to be part of the information carrier in the sonification. The harmony could, for example, become more dissonant when events need attention and action from the air traffic controller.

However, it was clearly recognized that a more complex interactive sonification, with information in several auditory dimensions including amplitude, timbre and harmony, would pose considerable demands on the air traffic controller's ability to interpret and act upon the resulting soundscape. Any extension of the proposed system in this direction would therefore require appropriate education and training for air traffic controllers (as is the case with any development of air traffic control systems, to be sure).

4. DISCUSSION

The formative assessment described above indicates that the proposed concept may represent a fruitful step towards the intended goal of supporting air traffic controllers in forming and maintaining a workable airspace Gestalt. As is normally the case with these kinds of assessment methods, we also gain insight from domain experts on potentially useful directions in which to orient further developments and refinements. However, the results of a focus group obviously do not represent empirical ground truth. In this concluding section, we aim to provide a more critical and balanced discussion of our concept, including aspects that were not addressed in the formative assessment.

In the interest of reproducibility, the full 30-minute sonification sketch is available to download for researchers who wish to experiment with the design concept reported here. http://www.itn.liu.se/~nikro27/ison2016/peripheralATC.mp3

4.1. Introducing audio to ATC

Contemporary air traffic control is completely dominated by visual information, and probably for good reason. As a consequence, it can be assumed that air traffic controllers today are selected for their visual abilities, among other things, but certainly not for their aural abilities or their musical aptitude. It might be the case that our proposed concept has considerable ramifications in terms of recruitment policy, admission testing, and training regimes – which in that case would probably represent an unrealistic cost/benefit trade-off. More development and broader testing will be needed to ascertain the general fit of airspace sonification with the existing organization, practices and staff of contemporary air traffic control.

4.2. Interactive sonification and workload

The focus group findings seemed to indicate that interactive sonification of peripheral information would be less appropriate in high workload situations, and this may indeed be the case. However, it is important to consider that the focus group reactions were formulated in relation to a specific sonification design as illustrated in the sketch. There is a multitude of sonification design options waiting to be explored for high-workload situations, including ones aiming at reducing workload or providing ambient attention guidance to cope with unexpected developments. As mentioned above, amenable design dimensions for such sonifications include amplitude as well as timbre and harmony. Detailing those options would further open possibilities for the air traffic controllers to interactively change and adapt the sonification based on perceived workload. We are looking forward to exploring this direction further in our ongoing work.

4.3. Sonification research contributions

To the best of our knowledge, there are no published studies focusing specifically on complementary sonification in air traffic control. In relation to the existing literature on sonification, we find that our present work may have some relevance in two directions. First, we find the use of musical sounds to provide opportunities somewhat lacking in approaches based on arbitrary or "natural" sounds, including the musical qualities of timbre, harmony and rhythm. This reasoning is to some degree similar to Barra et al. [2, 1] who used musical sounds, or an aesthetic connotation to sounds on the border between music and background noise, rather than simple audio alarms to minimize fatigue and annoyance to sonify web server performance for long-term monitoring. Furthermore, musical structures have an ability to convey a multitude of information to listeners quickly and intuitively [17], suggesting that musical sounds are well suitable for monitoring control systems such as air traffic control. Second, even though the notion of peripheral sonification in itself is far from new, we find that our choice of musical sonification of an overwhelmingly visual task introduces some opportunities to broaden our understanding of the concept. For instance, our work points to new and exciting research questions concerning the relative merits of continuous soundscapes compared with short repetitive approaches [7] or strictly musical treatments [6].

4.4. Further applications

Within the domain of air traffic control, it is straightforward to identify other potential uses of a complementary airspace sonification such as the one we propose here. Some examples include supporting the formation of the "meta-Gestalt" required for management of air traffic control and workload planning, and nonintrusive monitoring of the training of air traffic controllers in simulator-based training centers as well as on-the-job training.

From a slightly broader point of view, it is reasonable to consider the potential value of interactive peripheral sonification in other domains that are structurally analogous to air traffic control. Examples of such domains are readily found in, e.g., other areas of transportation (road, maritime, rail), process control and monitoring in industrial production.

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