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SOUNDSCAPE INDICES (SSID): ON THE DEVELOPMENT OF A SINGLE-VALUE SOUNDSCAPE INDEX

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In a previous paper presented in the 29th International Congress of Sound and Vibration (ICSV29), the developments on establishing "Soundscape Indices" (SSID) were outlined, including: the SSID Protocol for field soundscape survey and laboratory listening tests, establishment of an open International Soundscape Database (ISD), relationships among psychological, (psycho)acoustical, neural and physiological, and contextual factors including soundscape evaluation in different languages and cultures, a soundscape analysis tool for soundscape researchers (Soundscapy), and an integrated soundscape prediction model. This paper presents the current development towards a single soundscape index. Firstly, based on the ISD and the Soundscape Circumplex Model, a method has been developed to determine the distance between a given/designed soundscape scenario and an ideal/target soundscape scenario considering their differences and similarities, for the purpose of defining standard and bespoke soundscape perception indices. A first implementation of this method is demonstrated to propose a use-case soundscape index via the ranking of a number of typical soundscape scenarios, using a series of laboratory experiments, considering the overall soundscape quality evaluation. Consequently, a flexible framework for defining single-value Soundscape Perception Indices (SPI) is provided and a standard use-case index is proposed.

Keywords: soundscape, soundscape indices (SSID), single-value soundscape index, soundscape perception indices (SPI), soundscape prediction, soundscape model

1. Introduction

Along with the paradigm shift from conventional environmental noise mitigation to overall soundscape creation [1-5], Soundscape Indices (SSID) are being developed, as reported in the 29th International Congress of Sound and Vibration (ICSV29) [6-8], including: the SSID Protocol for field soundscape survey and laboratory listening tests, establishment of an open International Soundscape Database (ISD), relationships among psychological, (psycho)acoustical, neural and physiological, and contextual factors including soundscape evaluation in different languages and cultures, a soundscape analysis tool for soundscape researchers (Soundscapy), and an integrated soundscape prediction model [9-32]. This paper presents the current development towards a single soundscape index, which is the distance between a given/designed soundscape scenario and an ideal/target soundscape scenario considering their differences and similarities, for the purpose of defining standard and bespoke soundscape perception indices. The method is then demonstrated via the ranking of a number of typical soundscape scenarios, and consequently, a flexible framework for defining single-value soundscape perception indices is discussed.

2. Determination of a single soundscape index

The Soundscape Perception Indices (SPI) framework is a novel approach to quantify and compare soundscape quality across diverse contexts. It is grounded in the soundscape circumplex model, a robust theoretical foundation for understanding and representing the multi-dimensional nature of soundscape perception [33-34]. The SPI framework aims to facilitate a broader and more efficient application of the soundscape approach in various domains, such as urban planning, environmental management, acoustic design, and policy development.

As proposed in [34], the soundscape of a location, community or setting is considered to be the 'collective perception' of the relevant group of people (e.g. the users of a space or the members of a community). When measured using the soundscape circumplex, this collective perception creates a distribution of responses within the circumplex space which can be treated quantitatively. The SPI framework is centred around the concept of quantifying the distance between a test perception distribution of interest and a desired target distribution. This is achieved by first defining the target distribution, which could represent what is considered to be the 'ideal' soundscape perception for a given context or application. The test distribution is then compared to the target distribution using a distance metric, which quantifies the deviation between the two distributions. The resulting distance value serves as the basis for calculating the SPI, with smaller distances indicating a closer alignment between the perceived soundscape and the target distribution. It should be noted that a target distribution does not *need* to represent the ideal perception – any target can be set and the function of the SPI is to quantify the test distribution's success at matching that target. Therefore, the target could also represent the soundscape of another location, where the SPI value would quantify the similarity between test soundscapes and the target location, or the target could be a negative soundscape and the SPI would identify poorly performing soundscapes. The key is that the target is set appropriately for the task at hand. Whether a high SPI score reflects a good soundscape depends on whether the target set represents a good soundscape for that context.

To enable this framework, we have proposed improvements in how the distribution of perceptions in the circumplex are analysed. Soundscape circumplex distributions are most appropriately described as a bivariate skew-normal distribution [35] which accurately reflects the relationship between the two dimensions of the circumplex and that real-world perceptual distributions have been consistently observed to not be strictly symmetric. A circumplex distribution can be parameterised with a 2x2 covariance matrix Ω and 2 dimensional vectors for location ξ and shape α, written as [36]:

$$Y \sim \mathcal{SN}_2(\xi, \Omega, \alpha) \tag{1}$$

Fitting a bivariate skew-normal distribution to a sample of empirical circumplex data is fairly straightforward, using existing software packages such as `sn` [37] for R. Likewise, once the parameters for the desired target distribution are defined, the same software is able to sample from the distribution, creating a simulated dataset. An example of the resulting dataset for a 'vibrant' target are shown in Figure 1, alongside a sample soundscape drawn from the ISD [14].

Once the test data and the target distribution are defined, we then want to assess the similarity between the test and target in order to calculate the SPI. For this purpose, we use a two-dimensional Kolmogorov-Smirnov goodness-of-fit test [38]. The KS test is a non-parametric test which quantifies the distance between the empirical distribution functions of two samples, and provides a distance metric bounded by [0, 1]. Since the goal for SPI is to provide a score for how well the test distribution matches the target distribution, we first convert the KS distance to a similarity and scale from 0 to 100:

$$SPI = 100 * (1 - KS_2(P, Q)) \tag{2}$$

where P is the test distribution and Q is the target distribution. For the example provided in Figure 1 for San Marco, SPI = 70. One of the key benefits of this approach is that the same target distribution can be tested against many sets of circumplex responses and get a consistent rating score. It is also highly flexible, allowing a wide array of targets to be set, tailoring what exactly the SPI score represents.

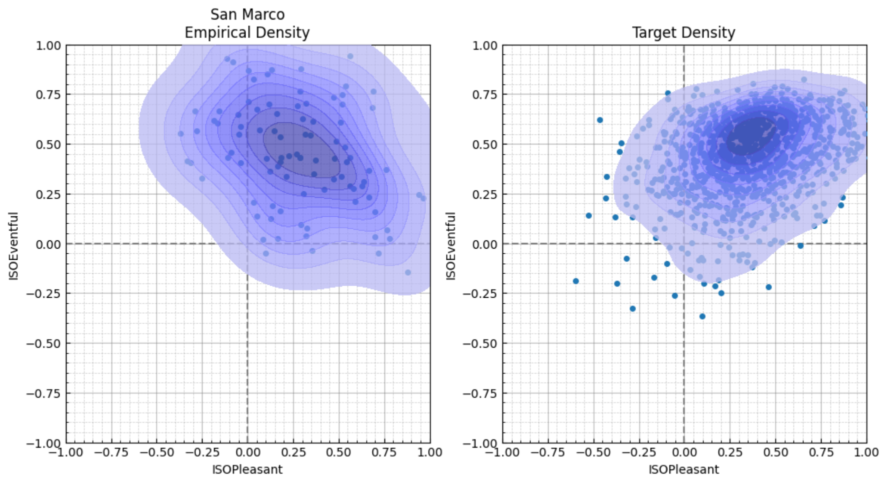

Figure 1: Soundscapy-style plots of soundscape perception responses in Piazza San Marco (left) and a bespoke target distribution (right).

Table 1: Soundscape Perception Indices (SPI) scores for locations from the International Soundscape Database (ISD), with a highly vibrant target.

Ranking	SPI_1 (vibrant)	
1	SanMarco	70
2	TateModern	62
3	Noorderplantsoen	59
4	StPaulsCross	58
5	TorringtonSq	55
6	PancrasLock	53
7	StPaulsRow	47
8	MiradorSanNicolas	46
9	RussellSq	43
10	CamdenTown	40
11	CarloV	35
12	MonumentoGaribaldi	34
13	CampPrincipe	33
14	PlazaBibRambla	32
15	Euston Tap	31
16	Regents Park Japan	26
17	Regents Park Fields	25

By calculating these SPI scores we can then rank the soundscapes according to their quality in different contexts. An example is shown in Table 2, with a highly vibrant target, generating SPI_1 score. It can be seen that for the two Regents Park locations, although they are both pleasant and calm parks and generally regarded as of high-quality soundscape, if we desire a vibrant soundscape as indicated by SPI_1 target, they are appropriately considered lower ‘quality’ than something like Euston Tap, a pub along a noisy road. If an appropriate target for a park were set, Regents Park would score more highly. The ability to summarise the multi-dimensional nature of soundscape perception and incorporate context by assigning an appropriate target, while remaining highly flexible by treating the target as a correctly defined distribution makes the SPI framework rather powerful. At the same time, although the technical details can be somewhat complicated, we feel that the concept of defining a desired soundscape character and creating a single score for how closely a soundscape achieves that quality is straightforward and easy to grasp.

3. Ranking of typical soundscape scenarios

The SPI gives a straightforward method for ranking soundscapes based on soundscape survey responses. However, Table 1 only shows the ranking against a relatively arbitrary target. How can we confirm whether this ranking appropriately reflects the actual ranking of soundscape quality people would provide? Beyond that, while the ability to define bespoke targets is useful, a method for deriving empirically defined targets is also necessary. In both cases, a proper ranking of overall soundscape quality is required. Collecting data on people’s ‘overall’ perception of the soundscape quality is quite difficult – given the multidimensional nature of soundscape perception and how context drives the quality of a soundscape, it is not enough to simply ask a single question. This is why we have based the SPI on the more specific descriptors from the Swedish Soundscape Quality Protocol [39] which can provide consistent in-situ responses. In order to obtain more consistent and holistic rankings of soundscape preference, we therefore propose using a paired-choice experiment in a laboratory setting, where participants can be asked to choose between two presented soundscapes, with a given use-case, namely urban open public spaces for relaxing/restoration. With such ranking results the weighting factors of the two dimensions in the soundscape circumplex can also be determined.

In the experiment 27 video clips representing various typical sound types, contexts and locations were employed, each of 15 seconds long with binaural recording and presented in VR. The result will produce a win-lose matrix and be used to calculate a single value of preference strength through the Bradley-Terry model [40].

The total possible number of paired comparison based on 27 videos is n (n - 1) / 2, resulting in 351 pairs. Considering the numbers and length of the video clips, it is difficult for participants to rank all clips at once. Hence, an alternative design was implemented to reduce such numbers. Based on Bradley and Terry’s [40] study, an incomplete paired comparison can considerably reduce the number of pairwise comparisons required without significantly impacting the reliability of the ranking [41-42]. One of the designs is *incomplete cyclic design*, where a minimum of 30% of data is required to achieve reliable ranking [42]. Figure 2 shows two examples of cyclic design implemented in the current study, where each arrow represents a pair comparison.

The current experiment utilised four such designs, each with 27 pairs of comparison, resulting in a total of 108 pairs of comparison (30.8% of the total possible pairs of 351), and each participant was only required to complete two cyclic designs (54 comparisons) at one time. The experiment was set up and conducted through the Head Acoustics system, and the pairwise comparison and data collection were handled by Artemis SQala.

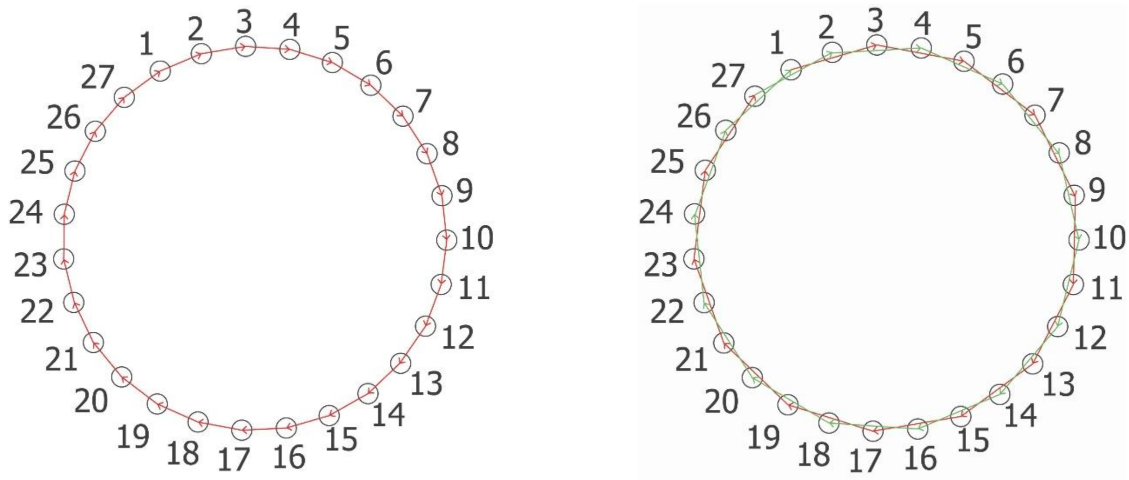

Figure 2: Two cyclic design examples implemented in the experiment, where each arrow represents a pair comparison. On the left there is one cycle and on the right there are two cycles, both with 27 pairs of comparison.

4. A flexible framework for defining single-value soundscape perception indices

For a given soundscape quality ranking and accompanying circumplex responses such as presented above in Section 3, we could derive an appropriate circumplex target which would give the same ranking. We could then be confident that the derived target description is representative of the character of soundscape that the respondents preferred overall. Consequently, a flexible framework for defining single-value soundscape perception indices is provided and a standard use-case index is proposed.

The SPI framework introduces two distinct types of targets: bespoke targets and archetypal targets. Bespoke targets, as described above, are tailor-made for specific projects, reflecting the desired soundscape perception for a particular application. These targets can be defined by stakeholders, designers, policymakers, or decision-makers based on their unique requirements, objectives, and constraints. Archetypal targets represent generalized, widely recognized soundscape archetypes which ideally transcend specific applications or projects. These archetypes can serve as reference points and enable comparisons across different domains and use cases. With a robust laboratory method to derive a ranking of soundscape quality for different contexts and the ability to optimise a target soundscape distribution based on that ranking, then the 'ideal' soundscape for a given context can be empirically defined. This ideal soundscape can then be assessed against new soundscapes, giving a concise, single metric.

It is clear that different contexts will have different ideal soundscapes. To demonstrate, consider the different use cases for an urban open public space. People can relax, or exercise, or socialise, or just travel through. If we consider a list of 15 different locations, they will be ranked differently for each of the use cases since they all have a slightly different optimal soundscape. We can then derive a recreation target, a relaxation target, and a socialisation target from these rankings.

Of course, soundscapes can be assessed against each target independently, scoring each soundscape for its suitability for relaxation (SPI_{rlx}) or exercise (SPI_{ex}). But we could also score each location only against its intended use case, thus making sure we are fairly assessing a given location only on its suitability for its actual use. Just because a quiet park scores poorly on SPI_{ex} doesn't make it a low quality soundscape – it could be appropriately scored against SPI_{rlx}. By doing this for each soundscape, an actual indication of context-dependent soundscape quality is built up. Since each of these independent SPI values are cross comparable, they can be combined together to produce SPI_{use}, a unified, single value index of soundscape quality for a given location's intended purpose.

5. Conclusions

In this paper, a method has been developed to determine the distance between a given/designed soundscape scenario and an ideal/target soundscape scenario considering their differences and similarities. The validity has been demonstrated through the ranking of a number of typical soundscape scenarios in laboratory experiments, evaluating the overall soundscape quality. Such results are also important for understating the weighting factors of the two dimensions in the soundscape circumplex. The consequently proposed flexible framework for defining single-value soundscape perception indices, namely SPI, can be used to aid the design process when a use-case based target soundscape is given, and can also be used to ranking different designs, for planning or design competition purposes, for example.

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