AMBISYNTH – MONITORING ROOM CLIMATE WITH GENERATIVE MODULAR SYNTHESIZERS

Markus Berger

University of Rostock
AI for Sustainable Construction
Rostock, Germany
markus.berger@uni-rostock.de

Joern Ploennigs

University of Rostock
AI for Sustainable Construction
Rostock, Germany
joern.ploennigs@uni-rostock.de

ABSTRACT

When engaged in focused work, it can be easy to forget about ambient comfort factors, like high CO2 concentrations or bad lighting conditions. Ambient Information Systems can help us passively monitor such parameters, but often have the downside of intrusive notification sounds or requiring visual feedback. In this paper, we propose to subtly communicate sensor information as part of generative ambient background music. This genre has recently been popularized through modular hardware synthesizers, which create music by processing analog voltage signals. We combine these modules with analog room climate sensors to create an “Ambient Information Instrument”, which will sonify the climate conditions of any room, without requiring digital processing or code. Aspects of the music become more noticeable as sensor readings exceed a set comfort range. Knobs and sliders on the synthesizer modules allow room occupants to interactively change and adjust the music being played.

1. INTRODUCTION

Certain public spaces feature background music in order to set a specific mood for their occupants. An elevator might play soft music to alleviate the tension of a tight space, a restaurant will play slow jazz to create a relaxed atmosphere and to smooth over kitchen noises, and a gym might play energetic music to accompany the workouts. In all of these cases, the music aims to stay in background while still having some subconscious effect on the people who are present.

What if we could use this background music to selectively drive attention towards issues within the space? In Ambient Information Systems (AIS), we employ sensor and display technologies to show information about a space, within the space. The aim here is not to offer a visualization dashboard, like in a traditional monitoring system, but to subtly embed sensor readings and alerts in the users surroundings. This is often done through visual means, one example being “traffic lights” that show CO2-levels within an enclosed space in 3 steps (red-yellow-green), in order to prompt occupants to intervene and provide more ventilation.

By employing techniques from the field of sonification, we can also encode this sort of information within sounds. Sounds can be used to confer information about our environment even when we are fully focused on something else. To achieve this, ambient sonifications often utilize real-world samples or other proxy sounds to act as auditory icons for the real phenomenon they represent. This is a good choice for certain systems, but also interrupts the existing soundscape with an intrusive signal.

In this paper, we thus want to investigate how we can encode environmental sensor data into the aforementioned background music, specifically room climate measurements like temperature, humidity, air quality levels or ambient light. The point of such a system would be to subtly drive attention to these environmental factors, without notification sounds that immediately disrupt what occupants are doing. Ideally, they would then be able to intervene, for example by switching on the lights or opening the windows.

In order to encode this sort of information in background music, this music needs to be generated on the fly, based on changing input parameters. A genre that fits this requirement and has recently been gaining popularity is generative ambient music. This music is most commonly created with modular synthesizers. These synthesizer are configurable combinations of individual modules that can be connected by a common signal standard, similar to analog computers. Voltage signals from one module feed into the next, which then modifies or otherwise works with this signal. The popularity of modular synthesizers comes despite the fact that they are based on seemingly outdated computing technology [1]. However, their mix of sound generation and sound modulation functionalities allows a level of sound synthesis that is usually not found in more traditional synthesizer hardware, and the ability to play and program them through tangible tactile interfaces without any need to configure software synthesizers invites exploration.

Here, we want to use signals generated by room-level environmental sensors, and feed them into such modular systems to generate ambient music. To achieve this, we will take the following steps towards planning and creating such “Ambient Information Instruments”:

- Collect relevant previous work in ambient information systems and sonification
- Establish a conceptual basis for how to use modular synthesis for ambient information display
- Discuss challenges and design considerations for the design of such systems
- Show a prototypical implementations to demonstrate the practical applicability of this concept

2. STATE OF THE ART

Developments in ambient information display, specifically for the built environment, by now have a long tradition [2]. However, with sensor, computing, and playback devices becoming smaller and more ubiquitous every year, there is still ongoing work. For ambient display in the visual domain, displays are becoming more and more embedded in the environment [3], and display-less information channels, like for example ambient light, can be used for passive data visualization that works even while focusing on another task [4]. Broadly, these systems fall under the umbrella of AIS, but do not describe the full extent of the term. There are already established taxonomies of their important aspects, like found in [5]. The authors adopt a definition for this term based on a definition for ambient *visual* displays from [6], in which AIS are defined as "aesthetically pleasing displays of information which sit on the periphery of a user's attention. They generally support monitoring of non-critical information."

Based on this, they define the following aspects of such a system: abstraction level, transition, notification level, temporal gradient, representation, modality, source, privacy and dynamic of input. These aspects can help in narrowing down design decisions. For the system in this paper, the most salient factor is the notification level, which the authors derive from [7], and describe as the level of attention that the display demands from of the user. It is divided into the following states: *demand action, interrupt, make aware, change blind, ignore*. For non-critical data that does not immediately demand action, the balance between the levels of *interrupt* and *make aware* is perhaps the most critical design distinction.

Another important factor is the used sensory modality. Many AIS default to a visual representation. However, because of the properties of our sonic perception, like our capabilities to listen all around us, it is sometimes recognized as a sensory modality that is especially powerful for ambient display. It is also in many respects still left untapped [8]. When using sound as a display modality, we can perform *Audification*, in which we directly translate time series data into a sound signal, or *Sonification*, in which we utilize a large array of established techniques to translate data into sound [9]. While sonification of environmental data has been of research interest for many years, both with more abstract [10] as well as more musical [11] sonification methods, the possibility of ambient sonifications has become more prominent through the miniaturization of playback devices and Internet of Things (IoT) sensors. The "WeatherChimes" project [12] is one example for this.

Sonifications that are deployed in the built environment specifically, usually attempt to passively monitor factors important for occupants of the space. Two examples are the "Powerchord" project, which uses real-time sonification to communicate the electricity use of household appliances [13], allowing people to control their energy consumption, or the "sonic carpet" project, implementing a similar sonification with an interactive component [14]. Many systems focus on notification sounds, like the "Noti-Fall" system described in [15], in which different sounds created by falling water notify room occupants about specific events.

Systems that try to be less direct about their notifications are described as "Blended Sonifications" in [16], where sounds and interactions created by the humans in an environment are what drives the sonifications, which use or extend these sounds to deliver information in a way that does not introduce any new, non-ecological sounds into an environment.

Many systems use this sort of technique, in which the sonification mirrors sounds that already exist in nature or the sonified environment itself, usually following the reasoning that sounds that fit the soundscape of a given space are less disruptive for auditory AIS [17]. On the other hand, [18] argues that user taste (perceived aesthetic attractiveness of the system) is important for ambient information displays systems especially. As such, in order to make them usable and effective, the intended user should be able to configure them such that they adhere to their background and aesthetic sensibilities. While this is possible in some of the aforementioned projects, for a music-based system specifically this leaves two options: Pre-configure a large number of musical mappings, in the hopes that the user will appreciate one or more of them. Or, let the user directly alter the music as its being played. To put the latter option another way: give the inhabitants of a room an instrument that they can play until they like what they are hearing, then let the instrument keep playing, and use sensor data to modulate the level to which the music grabs attention.

3. METHODOLOGY

3.1. Room Climate Sensors

Common types of room climate and comfort factors that we monitor with sensors are temperature, humidity, air quality, light, and noise. Air quality includes many different types of sensors, like for CO2 or particulate concentrations. Secondary sensor types that are often included in monitoring systems are occupancy or motion detectors, which are usually used for systems that also control ventilation and heating within the room. For the hardware monitoring prototype described later on in this paper, we will consider the following types of sensors: temperature, humidity, and light.

There are two main ways to approach a monitoring task for each of these sensors, regardless of whether we use visualization or sonification. We can either monitor them continuously, by mapping them to some variable that can describe the quantitative up-and-down of the sensor readings (e. g. color or pitch). Or, we can set certain threshold values at which events are triggered.

Because all the relevant sensors are continuous, and the design target is to keep the notification level to "make aware" within a piece of continually playing background music, continuous monitoring is the most relevant category here. Threshold values could be used, but would be more difficult to integrate into the musical flow without being jarring. Before we will consider the specific methodical details of how to use modular synthesizers for this purpose, the basic purpose of this sonification is illustrated in Figure 1.

3.2. Modular Synthesizers

Modular synthesizers are available in different standards, but they all allow users to buy individual modules for each step that a conventional "all-in-one" synthesizer would perform on the sound signal, from the moment sound is created or fed into the synthesizer, up to its output into a playback or recording device. For this, they not only allow the synthesis and alteration of sounds, but also include control signals akin to analog computers, which can control parametric aspects of the sound synthesis depending on the types of inputs offered by each module.

The processing done within the modules can be both analog and digital, as long as the output signal fits back into the analog signal standard. Both sound signals as well as control signals are

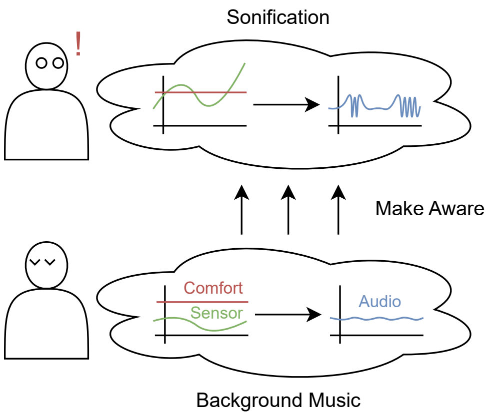

Figure 1: Once sensor values exceed a set comfort threshold, the sonification changes the background music in such a way that a room occupant slowly becomes aware of the change.

represented as voltages, and in many modules can be used interchangeably.

Because of the heterogeneity inherent to modular synthesizers, there is no generally accepted classification of modules. An overview based on a synthesizer-centric view can be found in [19], in which the authors create their own modular synthesizer as part of a tangible interface for sound synthesis. They give a list of the basic modular parts used in modular synthesizers and describe each of them: oscillators, low-frequency oscillators, amplifiers, envelope generators, filters, effect processors, mixers, modulators, sequencers. The authors also provide a list of common methods of sound synthesis, like physical modelling, frequency modulation or sampling. For this paper, we will instead divide modules into categories according to their use case within a music generation chain: sequencers, sound sources, audio effects, control modulation, and outputs.

Sequencers Any module that can arrange the sounds that other modules can generate in musical ways. This includes melody generators, clock sources and more. For non-generative music this can also include input modules that allow for direct manual playing, akin to conventional musical instruments.

Sound Sources Any module that can output sounds into the rest of the modular system, either based on simple oscillators, frequency modulation, physical modelling, sampling, or even external audio inputs.

Audio Effects Any module that can take an existing sound and change it in some way. Some of the most common types of effects are reverb generators, equalizers, and filters.

Control Modulation Any module that can receive, generate or alter control voltage signals, like oscillators, attenuators, or offsets.

Output Any module that takes an audio signal and transform it into an output usable by playback or recording devices.

The power of modular synthesizers in the field of sound design then derives from the fact that every module can be part of one or multiple categories, and all these modules can be chained together

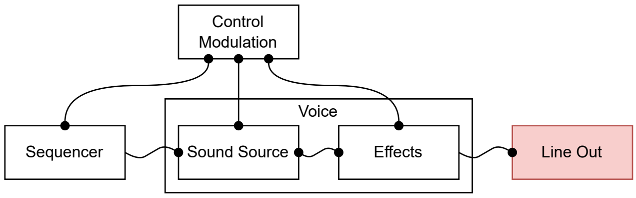

Figure 2: An overview of how a melody or rhythm is generated in a modular synthesizer. Not shown: multiple voices are possible, usually controlled by one sequencer.

in various ways. Modulators can modulate modulators, audio can be converted into control signals, the output can feed back into effects, and effects can become a sound source by themselves.

While types of modules are important to know when creating such systems, a more salient concept for their overall design is the concept of a *voice*. A voice is the result of a chain of sound sources and effects, that can then be played by the sequencer or by direct user inputs. It thus fulfills the role of an instrument in conventional musical sonifications, however a modular system can be used to create multiple interrelated voices that play at the same time or even modulate one another. Voices can be distinguished into pitched and percussive voices. *Pitched* voices feature sounds whose frequency corresponds to some musical scale, and can thus be played like a guitar, keyboard or wind instrument. *Percussive* voices usually consist of unpitched sounds that are played in rhythmic sequence, like drums. Fig. 2 shows an overview of the concepts introduced in this section.

3.2.1. Generative Ambient Musification

While modular synthesizers can create many different types of music, generative ambient music is one of their more common use cases, and probably gained popularity due to the fact that every modular synthesizer already includes modules that act as analog computers and clocks, thus inviting experimentation into circuits that not only produce sounds in a computerized way, but complete arrangements of music. Generative ambient music often is supposed to play for an hour or more without getting stale.

The modular, open nature of these systems makes techniques difficult to categorize, but for ambient music generation specifically the following are usually the most important:

Probabilistic playing There needs to be some way to trigger melodies and rhythms in a random fashion over time. This is either done by setting note probabilities, in which a clock creates a random note at certain intervals, or more advanced, sometimes evolving, forms of randomization.

Ambient Sounds To prevent the music from sounding too clean or boring, there should be sounds that are not strictly in rhythm and simply add additional texture to a piece. This includes pitched and unpitched sounds that are played for long periods of times (drones) or short, usually reoccurring, sound instances that can happen independent of rhythm and are often controlled to accompany the sequenced, rhythmic parts of the ambient music (samples, granular synthesis, bursts).

Silent Periods Silence is just as important as the sounds, as no piece will stay engaging if every voice in it plays at full intensity at all times.

Short-Term Modulation Sounds need to change moment to moment, in either periodic or random fashion. Examples of such modulations are frequency modulation, sampling, filter sweeps and any kind of other voltage-controlled effect.

Long-Term Modulation In order to keep a piece engaging for hours, there needs to be modulation running on very slow clocks. This kind of modulation will usually change factors like mixing, sound or CV generation algorithms or even which modules are activated.

3.2.2. Playability

Playing a modular synthesizer can be quite complex. Learning a module, especially modules with lots of input possibilities, can be similar to learning a new instrument. Any user interaction for playability needs to be to some degree abstracted. Users should ideally see some sliders, knobs and buttons they can use, and then find out what they do once they press or use them. Because everyone at least knows how to operate these basic hardware control elements (a knob has to be twisted, a button has to be pressed), they can be more inviting than more novel interaction system like for example grasping interactions for tangible objects [8] or motion-based tracking installations, in which possible interactions are often initially unclear and feedback somewhat delayed. The disadvantage of modular synthesizers is that for the layperson (and sometimes even more advanced users), the effect of the knobs, sliders and buttons will not immediately be apparent. However, it is fine to surprise people—switching to a new piece of music is in some ways a search for novelty after all. A long-time user will begin to understand which control elements create which effect.

Modular synthesizers that act as Ambient Information Instruments however exist in a space together with the occupants. Thus, a layperson exerting influence on the music generation should be a possibility. The challenge is to set up a modular system that can survive user interaction over multiple elements. For this, interaction elements that a user is allowed to interact with must be separated from those that are important to the logic of the system. To aid in this and in playability, it would be possible to mark certain control elements as easy and safe to play, making the system more inviting.

3.3. Sensor Musification with Modular Synthesizers

With these considerations in mind, there remains the question of how we take room climate sensors and a modular synthesizer capable of producing generative ambient music and turn it into a room climate monitoring system.

The first necessary step is to turn the sensor outputs into inputs for the modules in the modular synthesizer. There are different ways to do this in practice, from directly connecting analog voltage signals to using MIDI (Musical Instrument Digital Interface). Technical implementations for both approaches will be discussed in Section 4. The important part is, that in the end there will be a control voltage level for each sensor value (or derived value) that we want to monitor. These voltage levels can then be introduced into different modules, in order to achieve the desired effect.

The desired effect, as established previously, is to make room occupants aware of the fact that a certain value has left the range of comfort. Different types of modules offer us different ways of achieving this. Some module types are more appropriate for this task than others, as shown in the upper part of Table 1.

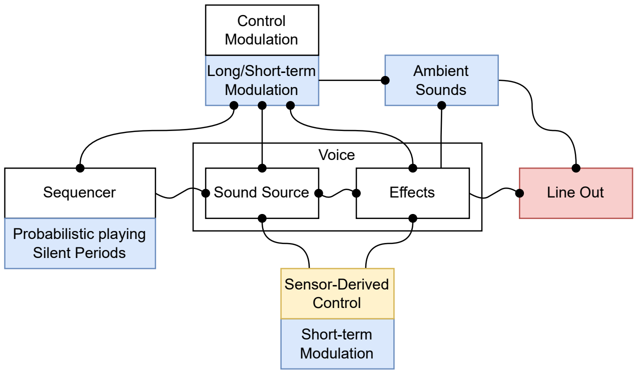

Figure 3: An overview of which modules implement which ambient generative music techniques and how the sensor voltages contribute to the music. Blue boxes show which technique is usually implemented by the respective modules.

An important consideration however, is the fact that these alterations to the played voices can not conflict with the generative music itself, so that listeners do not confuse random fluctuations with a sensor readings. Most of the time, the modular synthesizer needs to generate enjoyable background music, and only occasionally do we need to draw attention to a sensor value. Thus, we need to be mindful of the techniques we use to compose generative music, and leave enough space within for our sensor values. The lower part of Table 1 illustrates these differences. There we can see that short-term modulation is the most appropriate target for the sensor-derived control voltages, i. e. changes to sound sources and effects. We thus need to compose the generative ambient music such that it does not by itself create too many of these drastic short-term changes. This is not a large issue, seeing that the goal is to create background music, which calls for fewer dramatic changes by its nature. Figure 3 extends Figure 2 to show where in the modular music generation chain the different techniques and the environmental sensors will usually be included.

4. IMPLEMENTATION

To show how to apply these methods, this section will describe sample implementations of modular synthesizers as AIS. We will focus here on a fully analog system, as it most closely follows the idea of a modular synthesizer as musical analog computer. We will include a short concept for a virtual system at the end.

4.1. Analog Sensor Processing with Physical Synthesizer

The most common standard for modular synthesizers today is the “Eurorack” standard, which operates on 12 V of power, with both control voltages (CV), represented as direct current, as well as audio signals, represented by alternating current, usually operating between -5 V and +5 V. Both types of signals are exchanged between modules over 3.5 mm mono jack cables. Many analog environmental sensors, especially those built for use with Arduino microcontroller boards, also operate in this +-5 V range. By creating a circuit that feeds the analog output of these sensors into a 3.5 mm mono jack cable, it is possible to directly route the sensor readings into Eurorack modules as a CV, without any need for a microcontroller or digital processing. This allows on-the-fly rewiring not

Aspect	Effectiveness	Description
Module Type		
Sequencers	Low	Because sequencers deal with discrete events, encoding continuous sensor values is difficult. One possible input we could control is the tempo at which notes or rhythms are played.
Sound Sources	High	Oscillator, frequency modulation and physical modelling sound sources usually have many parameters that can be externally controlled. Certain input modules could also directly turn the sensor-generated control voltage into a drone instead of a melodic or rhythmic voice.
Audio Effects	High	Any audio effect that noticeably alters the voice is an appropriate target for sensor control. Usually this will be effects that filter or change the audio more drastically, not subtle effects like equalizers.
Control Modulation	Medium	These modules can further prepare the sensor-generated control voltage for other modules, but will rarely be the endpoint of the sensor control.
Output	None	Direct output of sensor signals will yield nothing but electrical buzzing.
Technique		
Probabilistic playing	Low	Changes to a probabilistic algorithm will be hard or even impossible to recognize subconsciously.
Ambient Sounds	Medium	Short ambient sounds would be more appropriate for event-based sensors, but longer droning sounds can be used to monitor continuous sensors.
Silent Periods	Low	Silence based on sensor values will be very difficult to distinguish from silence that is probabilistically generated.
Short-Term Modulation	High	By using more attention-grabbing effects than generated by the music itself, sensors can easily be cause short-term modulation that is very recognizable as sensor-induced.
Long-Term Modulation	Low	Long-term modulation can not react to sensor value changes in an appropriate time frame and would be difficult to distinguish from the non-sensor-based modulation.

Table 1: The effectiveness of each module type, and generative ambient composition technique, for turning sensor-derived control voltages into attention-grabbing music changes.

just of the musical component of the synthesizer, but of the sensor value processing too. This not only keeps the system fully explorable to the advanced user, but makes every aspect of the sound generation completely accessible and embodied within the space it is sensing.

One downside is that this requires a collection of modules to "calibrate" the output of the sensor to the required CV ranges. The signal needs to be shifted up or down with an offset module, so that the end of the comfortable range is where the effect on the background music is non-existent or at least inaudible. Then we typically need to make sure that the voltage increases as the sensor signal leaves the comfort range (with an inverter module) and does so in a value range that usefully translates to CV (with an attenuator module). Inverters and attenuators are often combined into so-called "Attenuverter" modules. A common issue then is that the value range of the sensor will be calibrated in such a way, that a simple attenuator can not increase the sensitivity of the signal to the point that the region from comfort to maximum value covers the whole five volt range. In this case, we can use amplifier modules, which usually are created to act as pre-amps for external audio inputs, in order to more drastically increase voltages. For safety and ease of configuration there are also logic modules that can stop the signal from leaving the sensor range in dangerous ways. Finally, we need a module that smoothes out noisy or sudden increases in sensor readings, as the voltages should not fluctuate on a timeline that can compromise the musicality of the sonification. This can be achieved through a so-called "slew" module. The complete idea behind this control modulation chain is illustrated in Figure 4.

The musical setup of the synthesizer directly corresponds with the conceptual ideas shown earlier in this paper. The synthesizer will have a sequencer playing exactly one pitched voice with randomly generated melodies. The sensors are then used to trigger different effects on this one voice.

Used sensors are temperature, humidity and light. The ambient light sensor will control aspects of the sound source, the temperature sensor will control direct audio effects, and the humidity will control a more indirect textural feedback effect. Temperature has a specific issue, in that it can very easily become uncomfortable both in the hot and the cold direction even in a controlled environment. While it would be possible to use a bipolar effect that is noticeably different in both positive and negative direction, the issue is that we only want to apply the effect once a comfort threshold is exceeded. Thus, we need to consider each direction its own sensor input with its own threshold. To achieve this, the temperature signal is split into different audio cables and CV-processed in two separate ways.

The sensor CV processing is kept simple, with an offset, an amplifier and a slew. A gate module would be helpful, but is not completely necessary, as the effects we plug into will already be limited to a certain range. We can simply set the comfort threshold at 0 and find a good amplification setting so that the expected sensor readings fill out the 5 V of signal space as best as possible. Because temperature sensors especially have a large value range, a strong amplification module is needed, in order to raise the small differences in voltage into the appropriate CV range.

Figure 5 shows the electronic circuit used to wire the analog sensor readings into 3.5 mm jack cables. Figure 6 then shows a full view of how these wires are patched into the Eurorack synthesizer, as well as the different signal processing steps taken on the synthesizer. Table 2 lists the used parts and modules. A video demonstration of this synthesizer playing and following sensor changes can be found in the supplemental materials of this paper.

The "Timbre" input of the Beehive module is controlled by

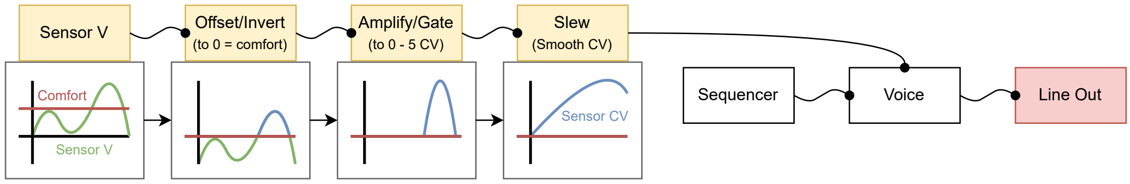

Figure 4: How a sensor signal is turned into a CV that can effectively induce change in the playing ambient music.

Part	Name
	Modules
Sequencer	Stochastic Instruments - SIG+
Sound Source	After Later Audio - Beehive
Effect (Ambient)	After Later Audio - Monsoon
Effect (Reverb)	Endorphines - Milky Way
Output	Intellijel - Line Out 1U
Offset	Noise Engineering - Sinc Pravus
Attenuverter	Intellijel - 1U Quadratt
Amplifier	Making Sound Machines - Thousand dB
Slew	Doepfer - A-171-4 Quad VC Slew Lim.
	Sensors
Temp/Humidity	DFRobot - Analog SHT30
Ambient Light	DFRobot - Analog Ambient Light Sensor

Table 2: A listing of the sensors and modules used for different steps in the sonification pipeline.

the ambient light, altering the spectral makeup of the sound and creating brighter and snappier notes. The "Harmonics" input of the same module is controlled by the temperature sensor, which creates a more fuzzy and synthetic sound by changing the spectral balance of the sound, similar to an equalizer. The humidity then controls the "Cabin Pressure" of the Milky Way module, slowly turning the distinct notes of the generative melody into a drone through a textural reverb effect.

It is important to note here, that these effects should not necessarily be chosen by how well they thematically or narratively correspond to the parameter they are mapping (e. g. the soundscape becoming darker as ambient light decreases). It is much more important that the mapped effect creates an appropriate level of awareness at the correct time. One sensor value might be less likely than another to reach the maximum of its range, and thus needs to grab attention more quickly in the mid ranges than a sensor value that shifts up and down more drastically. The exact mapping thus needs to be the result of a trial-and-error process that depends on the local conditions and the employed modules.

While this analog system already proved appropriate in a convention setting, i. e. for a space in which it is very quietly played alongside conversations as people transition through, it can quickly become repetitive when used in more solitary environments. Here, a system with multiple voices and a much more complex layering of long-term modulations would be needed.

4.2. MIDI Sensor Processing with Virtual Synthesizer

An analog system, like the one shown in the previous section, will quickly balloon in size once more complex circuits are required. For situations that call for a large number of sensor values, several long-term modulations, or even programmable behaviours, a

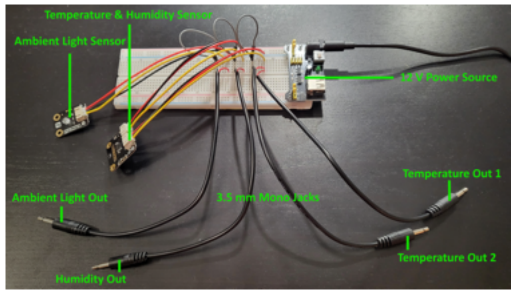

Figure 5: The circuit used to move from analog sensors to 3.5 mm audio jack.

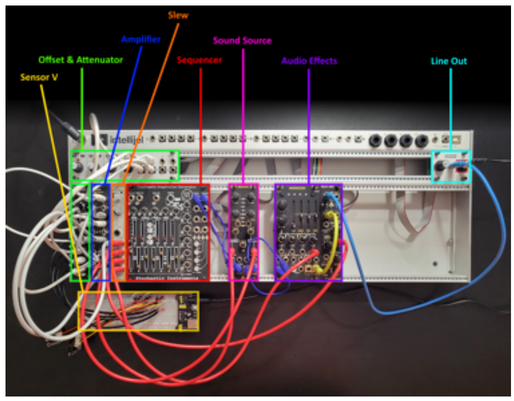

Figure 6: An overview of the full modular synthesizer with sensor inputs. White and grey cables are for connections that process the sensor signal, blue and yellow cables create the generative ambient music, and the four red cables connect the generated sensor CVs to the voice such that sensor changes become audible.

partially or fully virtualized system can be more appropriate

For such a system, we would communicate sensor values through MIDI instead of through 5 V analog voltage signals. Here, we connect the sensors to a programmable system (like an Arduino board or a PC) and then process the sensor data with a custom program. This can not be changed on the fly by occupants once the system is deployed in a room, but it is much more flexible during setup. The sensor values can be processed to have certain sensitivity curves, to bottom or top out at certain values, to trigger conditional alerts or to modulate each other, like in the case of temperature and humidity. The modular synthesizer then only needs a module that can take MIDI CC inputs and turn them back into audio or CV. Most of the control modulation chain can be left out, instead much more space can be devoted to different types of voices.

If direct playability is not as important, we can also keep the system entirely virtual. The simplest way to achieve this is by using a virtualized modular synthesizer, as for example enabled by the VCV-Rack software. This software implements many common types of modules (and even emulates specific modules), so that we can use the same strategies of generative ambient music as with a physical system, without the associated issues of cost and space. Such a system could easily be miniaturized and deployed in multiple rooms. If direct configurability is still desired, it could be connected to a touch screen that shows the VCV-Rack window and allows for interactions there.

5. CONCLUSION AND FUTURE WORK

In this paper, we showed how to implement a sonification of room climate sensor data within background music generated by a playable generative instrument. To achieve this, we utilized modular synthesis in combination with analog sensors. First, we highlighted the methodology behind modular synthesizers and ambient generative music specifically. Then, we devised a strategy of combining this type of music synthesis with room climate sensor readings. After establishing a set of design considerations and guidelines, we showed a prototypical implementation as a fully physically interactive, analog system.

In future work, the created prototype can be extended with multiple types of voices, for example to create sensor-driven percussion or ambience tracks. It could also be extended with novel input devices, that allow for more immediate playability or complex reconfigurations. A systematic user study could be conducted as to the effect of different configurations on room occupants.

The fully virtual system could be expanded into a framework, which could potentially take any configuration of sensors already available in a room (such as in facility management systems) and make them a part of a whole playlist of background tracks. The concepts shown in this paper could also be extended with other sensor types that create discrete events, and detect environmental factors that are critical enough to ask for higher levels of notification once they exceed a set safety range.

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