SnoeSky and SonicDive - Design and Evaluation of Two Accessible Digital Musical Instruments for a SEN School

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ABSTRACT

Music technology can provide persons who experience physical and/or intellectual barriers using traditional musical instruments with a unique access to active music making. This applies particularly but not exclusively to the so-called group of people with physical and/or mental disabilities.[1] This paper presents two Accessible Digital Musical Instruments (ADMIs) that were specifically designed for the students of a Special Educational Needs (SEN) school with a focus on intellectual disabilities. With *SnoeSky*, we present an interactive installation in form of a starry sky that integrates into the ceiling of a Snoezel-Room.[2] Here, users can 'play' with 'melodic constellations' using a flashlight. *SonicDive* is an interactive installation that enables users to explore a complex water soundscape through their movement inside a ball pool. The underlying goal of both ADMIs is the promotion of self-efficacy experiences while stimulating the users' relaxation and activation. This paper reports on the design process involving the users and their environment. In addition, it describes some details of the technical implementation of the ADMIs as well as first indices for their effectiveness.

Author Keywords

special education, accessible digital musical instruments, interactive, music education, music therapy, snoezel

CCS Concepts

•**Applied computing** → **Sound and music computing;** •**Human-centered computing** → *Interface design prototyping;* Accessibility technologies;

1. INTRODUCTION

The advances in music technology and the increasing availability of low-cost sensors and computers facilitate the development of ADMIs for educational and therapeutic settings, while at the same time promoting a gain in research interest and publications [5, 19, 8]. After the *Declaration of Human Rights* and the *Convention on the Rights of Persons with Disabilities*, active music-making can be regarded as a basic human right [5]. Obviously, this right presupposes the availability of accessible instruments.

[1]There is a long history of criticism on the terminology used to describe the complex phenomena of disabilities [16, 2, 10] that cannot be sufficiently addressed in this paper.

[2]A Snoezel-Room is a closed space provides multisensory stimulation in a soothing atmosphere. For more information see: `https://www.snoezelen.info/`.

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2. RELATED WORK

Existing ADMIs implement a wide range of different approaches. Digital musical instruments addressing specific abilities of particular users or user groups include for example touchless sensor instruments like the *Soundbeam*[3] and the *Globophone* [11], video-based instruments like the *MotionComposer* [4], breath-sensor-based instruments like the *Magic Flute*[4] and tangible instruments like the *Skoog*[5]. Many ADMIs provide interactive environments where users individually or collectively invoke and control sonic and/or musical events and processes, like for example *Blobmusic* [11], *Sound Forest* [6] or the *Sound=Space Opera* [1].

In her comprehensive review of ADMIs, Frid [5] notices that there are only few publications specifically addressing user groups with intellectual disabilities, while most developments focus on people with physical disabilities. Furthermore, the majority of ADMIs present only bimodal feedback and only 15% provide vibrotactile feedback even though the latter can support the feeling of control and thus self-efficacy.

Especially in Germany, most publications addressing the accessibility of digital musical interfaces mainly focus on the use of mobile devices [7, 13] what besides advantages like universal availability also evokes critique [9].

3. CONTEXT AND MOTIVATION

The ADMIs described in this article have been developed for a German SEN school focusing on intellectual disabilities. The project has been conducted in the framework of a multidisciplinary design workshop with a group of eight students enrolled in the Music Design program of the College of Music in Trossingen and the Media Design program of the Digital Media Faculty at Furtwangen University.[6] On the side of the SEN school, the project involved a group of pupils as well as their music teacher and further teachers who closely accompanied the pupils within the class structure of the school. This allowed the design process to take

[3]`https://www.soundbeam.co.uk/`

[4]`https://mybreathmymusic.com/en/magic-flute`

[5]`https://skoogmusic.com/`

[6]More information on the overall project can be found at `http://projektiavi.wordpress.com` and `http://www.imui.org`.

into account different points of view and create positive dynamics around the project among the actors of the school.

The project produced a set of five functional prototypes two of which are described in this article. The described prototypes have been selected for being permanently installed in the SEN school at the end of the project.

In the context of disabilities, accessibility generally refers to overcoming disabling barriers that exclude people from participation. What might be regarded as such a barrier or as participation depends on the context, the involved individuals and their objectives. [5, 12, 17] Accordingly, weather a DMI is regarded as accessible or not depends on the individual circumstances of the application. In a broader sense, a musical instrument in general can be seen as a barrier for everybody who has not spent a lot of time practising an instrument. Thus, eliminating intellectual or physical barriers to music making using digital technology may provide accessibility to a much broader audience. On the other hand, digital technology itself might be perceived as a barrier, amongst others, due to economical constraints or technical challenges regarding the setup and maintenance of complex devices and applications [18]. Consequently, it was important not only to include the pupils – as future users – into the design process to be able understand their interests, abilities, and needs, but also to include teachers and further staff to understand the possibilities and constraints of the school environment.

An important concept guiding the design process has been the notion of self-efficacy [3]. The concept is going back to the psychologist Albert Bandura and basically describes the belief of individuals to be able to have a positive impact on their environment. Referring to the development of individuals in social environments, the concept easily applies to and extends through music making as an actual social activity which, as Christopher Small points out, *"stand[s] as a metaphor for, ideal relationships between person and person, between individual and society, between humanity and the natural world and even perhaps the supernatural world"* [15].

With our developments, we seek to provide opportunities to extend the users' experience of self-efficacy – actually and metaphorically. The developed environments allow the users to invoke and control sound through everyday gestures and movements.

This paper will provide a detailed and transparent description of the technology used, including the electric circuits and sound synthesis implemented in Pure Data and Max. The corresponding patches are available for download[7].

4. DESIGN AND IMPLEMENTATION

The design process of the two ADMIs described in this article consisted of multiple iterations of prototyping and evaluation following the design principles outlined by Ward et al. [18]. The project started with an observation phase of one month, that allowed us to become acquainted with the children – their abilities, needs, and interests – and the teachers as well as the school premises. This first period of observation allowed for developing first ideas which have been developed into mockups setting up the ADMIs' basic functionalities as well as first sketches of sound design over the following weeks.

Especially in the early period, the design process was guided by the following questions:

- How do the ADMIs fit the children's abilities?
- How do the ADMIs fit the children's interests and preferences?
- How do the ADMIs integrate into the facilities and the everyday-life at school?

Apart from these questions we have been particularly attentive to the metaphoricity implied by the ADMIs' setup and the afforded interactions. The goal was to create joyful and poetic environments that allow for positive and inspiring experiences. After a first selection of the most promising ideas based on sketches and mockups started a development period of several month.

Figure 1: The Snoezel-Room

4.1 SnoeSky

The basic idea of the *SnoeSky*[8] installation was to design an ADMI that blends in the concept of the Snoezel-Room (see figure 1) and also uses the technical elements available herein. Since the concept of the room lies in relaxation and multisensory stimulation it seemed to be adequate to extend the room with optional audiovisual elements such as soothing sounds and gentle lights responding to slow interactions.

Considering that the Snoezel-Room invites the children to relax on the waterbed the emplacement of visual elements on the ceiling was an obvious choice. This consequently inspired the idea of basing the visual elements of the installation on star constellations. The final prototype integrates 65 yellow light dots distributed over a black surface of 1.2 by 1.2 meter fixed on the ceiling above the bed. The light dots are realised through LEDs embedded into a black wooden panel at the approximate positions of the principal stars of eight constellations.[9] One of eight note pitches on an overtone scale is associated to each constellation. A slowly decaying note is triggered each time a flashlight is pointed to the corresponding constellation and rendered through the loudspeaker system of the Snoezel-Room. Due to the notes' long release, slow melodies and chords can be played by moving the beam of the flashlight over the constellations.

[7] *SnoeSky* is available at `https://github.com/imui-org/SnoeSky` and *SonicDive* is available at `https://github.com/imui-org/SonicDive`.

[8] The name *SnoeSky* is a concatenation of *'snoezelen'* and *'sky'*. A short video of children using the installation is available at `https://vimeo.com/412368397`.

[9] The constellations formed by the light dots are *Boötes* (or *Herdsman*), *Cassiopeia*, *Cepheus*, *Corona Borealis* (or *Northern Crown*), *Cygnus* (*Swan*), *Draco* (*Dragon*), *Ursa Major* (*Great Bear*), and *Ursa Minor* (*Little Bear*).

The interactive audio synthesis of the installation (see figure 2) implements a one-to-one parameter mapping in which the decaying envelopes of each of the eight voices are triggered through a photoresistor embedded into the wooden panel in the center of each constellation. The sensitivity of the photoresistors is adjusted to capture the beam of a small flashlight being held by a person lying on the bed below the panel. Each note sound is synthesised by a noise oscillator shaped into a pitched sound by a strongly resonating filter. Controlled by an envelope generator with a relatively short but smooth attack and a long release time, the emerging sound quality has a soft resonating timbre of 'shining' texture. This synthesis technique can be seen as a simple model of a resonator that is excited by a stroke. Other than repeatedly triggered sound samples, it results a lively sound quality with a relaxing effect that is well accepted by the users.

Figure 2: Final installation of SnoeSky

To further enhance the relaxing character of the sound design, the notes triggered by the flashlight appear on the background of a meditative sound ambience. A constantly changing harmonic background is generated by two randomly breathing sounds that are generated in a similar way as the triggered notes, but with very slowly pulsing envelopes. The background ambience is completed by a low drone sound that particularly excites the subwoofer below the waterbed.

The installation runs on a *Bela* device[10]. The Bela platform has been chosen for the possibility to easily create a standalone installation including sensor inputs and audio output programmed trough the visual programming environment *Pure Data*[11]. The computation power of the device is sufficient for the simple polyphonic sound synthesis required by the installation. However, some additional components of the initial sound design prototype running on a laptop had to be omitted due to the limited computation power of the Bela device running the final prototype.

To provide a direct feedback that supports the feeling of actually creating the sound, we used a short attack, thus providing an impulse combined with the illumination of the LEDs. In the final installation, the direct feedback is emphasised by the low frequencies output by the transducer in the waterbed. When lying on the bed, the low frequencies can be felt as vibrotactile stimulation. In an earlier prototype, we tried to use frequencies in a very low frequency range (20 - 80Hz). However, after testing, we found that frequencies in the range from 100 to 200 Hz were more pleasant as auditory as well as tactile sensation. Due to CPU limitation we used three different sine oscillators that each are associated to the sound of multiple constellations.

[10] https://bela.io/

[11] https://puredata.info/

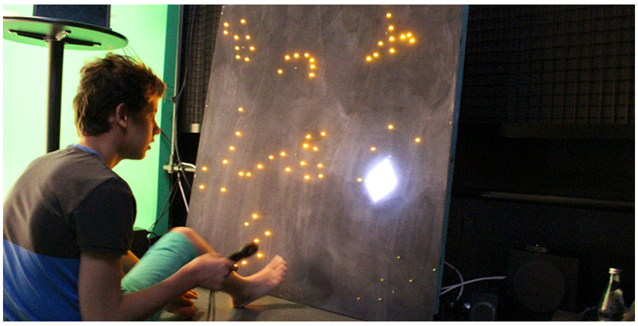

Figure 3: A child testing SnoeSky

To create congruency between sound and light intensity, the LEDs are driven through pulse width modulation controlled by the sound intensity using an envelope follower. Due to the limited current on the digital pins from Bela we use an external 15V/0,8A stabilized DC power supply for the LEDs. To close the circuit only when needed, a LR7843 transistor is combined with an optocoupler triggered by a digital output signal from Bela. The lights are set up in rows of 6 yellow LEDs each[12], which are combined in series to form the constellation. If the number of LEDs of a constellation is not a multiple of 6, the row is completed with 120Ohm resistors replacing the missing LEDs (see figure 4.1). The photoresistor is connected to an analog pin of the Bela board through a standard voltage divider circuit.[13]

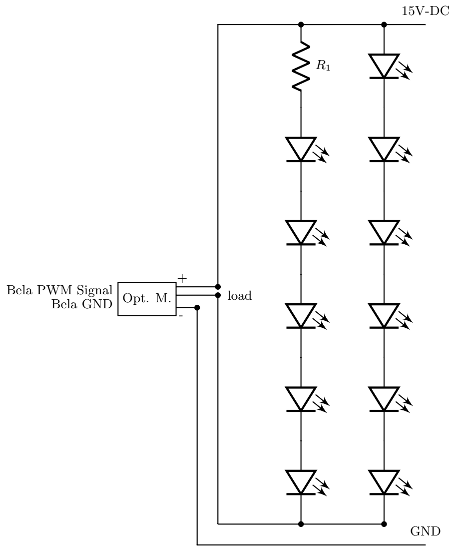

Figure 4: Simplified Example of LED Circuit

4.2 SonicDive

A *ball pool* is situated at the top floor of the school in one corner of a larger space including different areas constructed for play. Although it represents an opportunity for the children to exercise free movement, the ball pool has been used only very little. This situation inspired the concept of an interactive interaction based on the metaphor of swimming and diving, creating an immersive experience

[12] 20mA, 2,5V

[13] The electronic circuit is described here: https://www.instructables.com/id/How-to-use-a-photoresistor-or-photocell-Arduino-Tu/.

where the physical sensation of the ball pool is augmented by sound.

Using a camera sensing depth, the postures and movements of a user playing in the ball pool control a complex soundscape consisting of a generative ambience and interactive water sounds. Hereby, different sound ambiences are associated to motion below and above the water symbolized by the balls as well as to particular movements like diving into the pool or splashing water.

The users' movement in the ball pool is measured using a Kinect sensor mounted above the pool. The applications runs on a Laptop programmed with Cycling '74 Max[14]. The image processing is based on the cv.jit package for Max by Jean-Marc-Pelletier[15] and the communication with the Kinect is handled by the dp.kinect external by Dale Phurrough[16].

The mapping of the motion data to the sound synthesis distinguishes between the overall movement and the movement in certain areas of the pool. The depth image is used to distinguish motion above and below the surface of the balls in the pool. Open computer vision is used to perform a simple blob detection distinguishing smaller and larger objects moving on the surface of the pool (see figure 5). While smaller objects like a hand raised or a ball thrown above the surface induce smaller sound events like splashes, the detection of bigger objects like the users' body is used to distinguish between motion diving below and emerging above the virtual waterline. The detection of motion in certain areas of the video is separated into two distinct modes. In the first mode, the video is divided in four equal squares. The second mode consists of 100 equal squares. For movement detection the difference between successive frames is calculated and smoothed over time.

The corresponding sound design is composed by multiple elements. The background ambience is generated by a generative sound engine that plays back segments of a piano chord sample, back and forth with constantly changing start and end positions. The synthesis of water sounds of different intensity is mapped to the overall amount of motion. The engine cross-fades between three layers of different sounds corresponding to different levels of intensity. Each layer consists of a constantly changing sequence of random samples associated to the same intensity level. To create a realistic impression of moving water like, for example, a wave that rises and slowly abates, the amount of motion has to increase quickly and then slowly fade to zero. The detection of motion above the surface and under water is translated into the control of a lowpass filter. Underwater sounds are characterised by reduced high frequencies. The transition between above and under water is accompanied by a corresponding sound of moving water.

After testing different sounds and interactions with a group of children, a final version sound design was elaborated. In this mapping, small movements in a certain area, with a low overall amount of motion, trigger different sonar like sounds associated to the coarse grid (4 squares) and wind chime like sounds associated to the finer grid (100 squares).

Part of the generated sound is sent through an effect chain consisting of a long reverb, a lowpass filter, and a delay line. When the overall amount of motion exceeds a certain threshold each passing through the delayline is pitch shifted, thus creating a downward motion in pitch and timbre.

Additionally, smaller objects exceeding a certain height above the surface, like a ball thrown upwards, trigger sounds of splashing water.

In the final prototype we expanded the interaction with a visual component (see figure 5) using an existing video projector mounted above the ball pool.

4.3 Preliminary Evaluation

While our main focus was the development and design process of the instruments, we also collected some data from informal observations and discussions with the teachers. This first evaluation was accompanied by the same questions that already guided the design process. The test groups were formed by 5 to 10 children and not every iteration could be tested with the same children and the same amount of time. While the children's cognitive abilities varied broadly, there were no children with severe physical disabilities present.

How do the ADMIs fit the children's abilities?

On the one hand, we did not observe any barriers for the children using the basic functions of the two ADMIs. Even if the interaction of inducing sound and light through the beam of a flashlight does not correspond to any phenomena in the real world, most children using *SnoeSky* could intuitively understand the basic functioning of the installation without needing any explanations. For the few exceptions, we observed that the children explained to each other how the interaction works. For *SonicDive*, the children seemed to directly understand the water metaphor. We observed typical swimming movements like arm strokes or *holding one's nose while diving* and one child even took a header. On the other hand, we obsevered technical barriers regarding the teachers. One teacher used *SnoeSky* without sound due to a wrong adjustment of the amplifier. The teacher was astonished when we showed her the full functionality during a test session.

How do the ADMIs fit the children's interests and preferences?

During the short period of testing we observed that the children were deeply focused on the exploration of the sonic possibilities and seamed to enjoy the interaction. This impression was also confirmed by the teachers feedback, for example by one teacher telling us how the children repeatedly asked to use the installations. We observed some children laying down or performing slow, dance-like movements in front of the testing setup of *SnoeSky*, while another child was playign the instrument. One teacher even told us, that a child using *SnoeSky* normally never acts so calmly and focused. Most children seemed to enjoy the exploring of the sonic possibilities in the interaction with *SonicDive*. Some children repeatedly played with the *over-under-water*–impact while laughing out loudly. In most cases and for both ADMIs, for most children the testing sessions of 5 to 10 minutes each seemed to be too short. The teachers had to stop the children from exploring so that every child got the chance to test. We observed some exceptions for *SonicDive*. Especially the children with mild cognitive disabilities got bored after some testings, asking for different videos and sounds.

Both installations seemed to be especially appealing to the 3 children with autism spectrum syndrome. For example in the second testing one of those children came directly to us, took the flashlight and sat down in front of *SnoeSky* without even waiting for any greetings or instructions.

With *SonicDive* we observed a broad variance in the kinds of movements the children performed. Some performed huge movements, while some mostly performed delicate movements investigating the affordances of the new environment. So we had to adapt the interaction possibili-

[14] `https://cycling74.com/`

[15] `https://jmpelletier.com/cvjit/`

[16] `https://hidale.com/`

ties multiple times, to react to those smaller movements.

Even though the interaction design of *SnoeSky* is rather constrained, during evaluation (see figure 3) we observed that some children using the installation developed their own playing techniques. For example, the children changed the focus of the flashlight playing several notes at once, retriggered the same ones in different tempi, alternated between two notes in different tempi (tremolo) and created melodies or soundscapes of different densities. Altogether the children extensively explored the instrument in extended sessions lasting up to 20 minutes. Most of the sessions would have continued if they were not interrupted by the teachers.

Considering, that too much sensory feedback might be overwhelming for certain users [5], we integrated the possibility to directly turn off the vibrotactile feedback at the sound system. Unfortunately, this way most users are not able to choose for themselves if they want to turn it on or off.

How do the ADMIs integrate into the facilities and the everyday-life at school?

The current prototype of *SnoeSky* has been permanently installed in the school, so it can be tested and evaluated over a longer period of time. It is easy to activate using a switch that turns on Bela, with the Pure Data Patch loading automatically. In addition, we designed a pictured step by step instruction on how to use the installation. Some teachers already used the ADMI outside of the testing setting. Furthermore, the interaction through the flashlight makes that the users' physical interaction with the installation is limited to a strict minimum, which significantly simplifies its maintenance. *SonicDive* has not yet been permanently installed.

The costs for the material necessary to build *SnoeSky* add up to about 350 Euros in total. The installation has to be mounted on the ceiling, but is completely standalone and perfectly integrated in the space without requiring any particular attention and without interfering with any activity. Building *SonicDive* only implies costs of 50 Euros for the Kinect sensor and the corresponding Max external. However, the installation requires a Windows-based computer to run the software that has to be integrated into the installation or setup and connected each time the installation is used. On the other hand, the *SonicDive* installation can be setup in a few minutes at any ball pool.

5. DISCUSSION

The ADMIs described above follow two very differing approaches to ADMI design. While *SnoeSky* appears as a conventional tonal musical instrument that allows for playing melodies and chords through an interaction accessible to a large range of users, *SonicDive* can be more easily classified as an interactive sound installation. In summary, the first evaluation of both ADMIs led to positive feedback from both pupils and teachers, with some exceptions for *SonicDive*.

The users mostly seemed to enjoy the direct and intuitive relationship between motion and sound. While the observed creative exploration of *SnoeSky* confirms Rokeby's statement that *"constraints provide a frame of reference, a context, within which interaction can be perceived"* [14], the constraints of *SonicDive* led to some children being bored. One solution to this problem would be to add more variance to the sounds or even let the children switch between different *worlds*, keeping in mind that more variance might be overwhelming to other children. In general, the question of long-term engagement has to be evaluated over a longer period of time.

Furthermore the observation of teachers using *SnoeSky* shows that it is very important to design the ADMIs self-contained and to provide a detailed and easy to use instruction.

The data collected can only give a first impression and has to be interpreted carefully. To validate the observations further and more structured evaluations have to be conducted, most importantly with constant groups of children over a longer period of time. Additionally, the observations and their interpretations should be validated by interviewing the children and their teachers.

Especially during the testing of *SonicDive*, the observed pleasure of the children with severe cognitive disabilities might be partly explained by the promotion of self-efficacy experiences.

Since it seems to be a general problem in SEN school settings to get steady access to the same children and follow a schedule, it might be a good idea to also include the teachers in the evaluation process and have them collect data as well. Furthermore the observation time should be adapted to the individual needs of the children. It might also be a good idea to observe the children in individual settings. The teachers tend to give instructions to the children that might disrupt their individual way of exploring.

Although, we did not observe any barriers while the children were using the ADMIs, we want to stress that intellectual barriers are hard to uncover. While physical barriers are mostly visible, intellectual barriers are highly subjective. To uncover them one needs to know the individual person and be able to interpret her or his behaviour or statements.

Mainly *SonicDive* might not be accessible to users with severe physical disabilities, but both ADMIs yet have to be tested with this user group.

6. CONCLUSION AND FUTURE WORK

We have described the design and implementation of two ADMIs developed during a one-year workshop in collaboration with a SEN school. While one installation has been successfully setup in the school, the other will hopefully follow soon. The final prototypes have been well received by pupils of the school and the final evaluations seem to confirm the design choices made.

Nevertheless, a few weaknesses could already be identified which call for future improvements. For *SonicDive* we would like to find a solution to provide better accessibility to users with severe physical disabilities which would allow for setting up the installation in different SEN schools as already planned. In general, we would like to test – and possibly adapt – the installation with larger ranges of users of different ages and abilities.

Since the sound and interaction design of *SnoeSky* is rather limited we would like to integrate further controls to vary scales and timbre from one session to another. Integrating parameter automation would allow the sound to evolve over time especially when single constellations are illuminated for a longer period of time or repeatedly. Future extensions of *SnoeSky* could integrate the possibility to repeat note sequences played by the user in a loop. This *loop*-function is already implemented but disabled in the current prototype to simplify the interaction.

The permanent implementation of the installations at the school will allow for evaluating them over a longer period of time. For this purpose, the teachers are asked to collect observations in a diary and regularly make photos of sessions with the children.

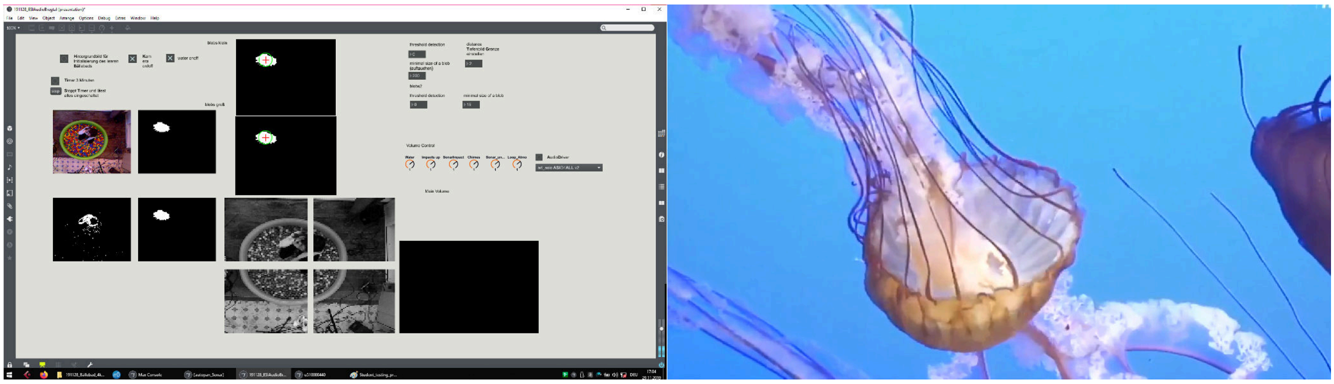

Figure 5: Testing SonicDive - patch and video view

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