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AMIGA - An interactive musical environment for Gerontechnology

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Abstract

Benefits provided by music in humans have been reinforced through several studies, mainly by active participation in musical therapy sessons, with surprising results in physical and psychological rehabilitation. However, all the previous implemented approaches require specialized hardware to function and complex configurations to set-up. We define a computational system focused on the elderly to allow musical expressiveness through motion, solely using the resources available in an ordinary home computer. To evaluate our approach, we developed a prototype and piloted acceptance tests on several senior citizens, with an average age of eighty-three. Our experiments showed high levels of interest from the senior citizens, denoting positive capabilities of well-being and life quality enrichment. The performed experiments have also shown that an ordinary computer is capable of performing the proposed methodology, without any restriction.

Keywords: Gerontechnology; Accessibility and usuability; Assistive Technology; Human-computer interfaces; Sound Design; Computer Vision

1. Introduction

The reality of the demographic situation in Europe is clear: the increase in average life expectancy and the low birth rate has caused aging of the general population. According to statistic data from the United Nations [1], in the past sixty years there has been a 160% increase in the world population, however in Europe the

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increase was only 36%. The same source revealed the mean relation between the elder population (above 64 years) and the youth population (up to 15 years) in the world is of 0.25, while in Europe this relation is about 1.017. These values demonstrate that, although in the world there's a proportion of four children for each senior citizen, in Europe it is closer to one to one, effectively having more elders than youths. The population growth rate has decreased over the years, according to statistic data published by Eurostat [2], since the populations growth rate in Europe between 2001 and 2010 was 3.8%, when the same rate between 2010 and 2011 was only 0.2%. Life expectancy at birth has increased in 7 years for males and 5 years for females during this period, currently standing at 77.5 and 82.6 years, respectively.

With aging, the individual suffers from both biological and social deterioration, gradually degrading his quality of life and autonomy. Although society provides social support, it is scarce in resources and out of range, as many elder live in remote locations, far from metropolitan areas. As for those who live in the cities, the metro community absorbs them where the lack of empathy prevails. There is also a high level of illiteracy and info-exclusion in the senior class, constraining their access to technology and electronic services capable of providing benefits. As in all of technology, the issue is not at the user level, but at the application level, due to a lack of compliance in accessibility design of software and services, which enhances overall rejection the elderly have with new technology [3, 4].

Confronting this emergent reality is Gerontechnology, focused on "designing technology and environment for independent living and social participation of older persons in good health, comfort and safety" [5], helping elderly accessibility and inclusion. Graafmans et al. define Gerontechnology as "the adaptation and development of products, services and environments to the needs of an aging population" [6] and, according to Melo, Gerontechnology applications can be categorized into five major aspects: "enhancement, prevention, compensation, care and research" [7]. This technological branch allows the development of new ambients, stimulating new activities and ambitions, and anticipating problems, actively preventing risk situations. In scenarios where prevention is not viable, it allows to support and compensate the individual, or helping health care professionals in the aid of the elder. Finally, it allows the investigation of the previous aspects to discover, analyze and develop new solutions in elder support.

1.1. Motivation

"Music is one of the most intriguing and joyful domains of research and analysis" [8], as it affects us in strange and yet incomprehensible ways with much to investigate, tendentiously related with the personal interests of musical investigators. The benefits music has in humans have been reinforced throughout various studies, mainly through active participation in musical therapy sessions [9], with surprising results in physical and psychological rehabilitation, normalizing adverse behavior and increasing social interaction capabilities.

However, the benefits of music are hard to explore by the majority, due to the expensiveness and inaccessibility of musical equipment and necessary knowledge in music theory. Technology has been exploited to develop unique means of musical expressiveness with digital musical instruments, where existent solutions with accessibility in focus have simplistic and unostentatious sonic characteristics, while complete and intricate solutions reject the most basic accessibility guidelines. Most solutions are complicated to set up and configure, requiring expensive equipment and technical supervision to operate. The necessary techniques and technologies for developing an autonomous solution prepared for Gerontechnology exist and have the potential for aiding not only the elderly and chronically ill patients, but also the general population [10].

2. Literature revision

It is important to establish the scientific effort carried out in investigating the beneficial effects of music and in developing of existing projects to promote and provide such advantages to the population. This section focuses on the literature revision, describing the fore mentioned effort.

2.1. Musical therapy

In the pursuit of exploring medicinal avails, the term "musical therapy" was introduced by Stige as "the study and learning of the relationship between music and health", applicable as a professional procedure [11]. Bonde defends that active participation of a subject in therapeutical music sessions, even without supervision or initiative by a professional, can introduce physical and psychological benefits, "creating meaning and coherence in states and times of adversity" [9]. Musical therapy sessions have generated favorable impressions in psychiatric consumers when compared with other types of treatments, according to Heaney [12] and Silverman [13, 14]. Paul and Ramsey [15] emphasize the potential in physical recovery and clinical maintenance in musical therapy, where the patient is actively involved in the musical process, instead of only reacting and responding to musical stimulus.

Grocke et al. [16] published a study revealing the assertive benefits of group musical therapy sessions on life quality for individuals with severe mental illness, and several authors like Glynn [17] and Fischer [18] support the exploitation of music as a mean of intervention for patients with Alzheimer's disease. Norberg et al. [19] demonstrated that patients in the final stage of Alzheimer's prefer auditory stimulation rather than visual presentation of objects and physical contact, and Hamer [20] developed behavioral strategies in non-functional patients with chronic dementia with musical therapy. Pollack and Namazi [21] noticed an increase in social interaction when subjecting Alzheimer patients to musical therapy and Clair and Bernstein found patients continued to respond to the therapy as their illness progressed [22]. When subjecting mentally ill patients to musical therapy, the resulting behavior is not as expected: instead of having a high level of agitation and aggressiveness, the subjects started smiling, laughing, clapping and dancing, diminishing their former agitation and aggressiveness [23, 24].

2.2. Gerontechnology in musical environments

Albeit music has triggered interest in clinical investigators, there has been scarce effort relating elderly with music, as the focus has been on specific illnesses. Specialists emphasize the advantages of applying musical sessions, even when self-prescribed, but it is hard to guarantee accessibility in active musical therapy due to the resources involved. By the definition given by Graafmans et al. [6], applying Gerontechnology to musical therapy would be adapting existent mechanisms and technologies to allow autonomous participation of the elderly in musical therapy, in order to explore and provide the related benefits.

In addition to creating systems for passive participation in sessions, where the patient merely listens and selects what they want to hear, IT systems can allow active participation in the sessions, generating sounds and music through digital musical instruments. Sound, in traditional acoustic music, is achieved through expressive manipulation of acoustic instruments with human gesture, whereas musical performance in computerized music implies an interaction between the human and a digital instrument, resulting in audible and visual feedback [25]. Wanderley [26] accentuates on the expressive capabilities of digital instruments, as they are free of physical constraints of real-life objects, noting the need for creating strategies to achieve a similar level of precision and detailed control as in acoustic instruments.

Kia [27] states "the body motion and gesture, directly and indirectly, contribute to various important factors of artistic performances", as for example the timbre of an instrument. The author presents a framework for research called "Music via Motion" [27], based on mapping detected variations in an environment to audio-visual events. Kia uses motion detection technologies like Computer Vision (CV), applied on augmented acoustic instruments with sensors, in order to capture the performer's expressiveness, which is linearly mapped to predefined actions such as audio and video generation, or automation of robotic equipment. This framework intends to capture the expressiveness and sonic capabilities of acoustic instruments, accurately simulating the interaction with digital instruments. However, this solution depends on a vast array of equipment, jeopardizing its autonomy and pushing it away from Gerontechnology. It also requires a specialized technician to install and configure.

During their investigation, Ellis et al. [28] created the iMUSE project related with Gerontechnology, addressing the concept of interactive multi-sensory environments to enhance life quality of the elderly and children with special needs. This project explores sound and image generation with accessible interfaces based on movement, studying both physical and psychological rehabilitation capabilities with a modus operandi of non-invasive active musical therapy. Brown and Ellis [10] published the results after 10 years of the creation of the iMUSE project, presenting positive results in subject response and independence. Despite their model generated motivation using natural curiosity and ludic pleasure, producing a huge impact on the state of mind, behavior and physical control of the tested subjects, it is not focused on user autonomy, as it requires technical supervision and uses a vast and expensive amount of specialized equipment. It is also very complex and difficult to replicate, diminishing its potential by limiting the product's availability, and only generates simple sounds, without musical context, using monophonic composition based on the chromatic scale.

Gorman et al. [29] used a simple video capture device to develop a human interaction project with real-time motion recognition called "Music Maker" that generates music for therapeutic exercises. Their solution applied CV technology to recognize the subjects' motion using the OpenCV library [30], generating simple sounds based on a static mapping of zones in the video stream, and presenting visual feedback to the subject. The authors tested a prototype with individuals having physical impairments and with an elderly subject, generating positive results, as all users could successfully and efficiently use the system, thus concluding that their solution has strong potentialities as a therapeutic device. Nevertheless, the simplicity of their sound mapping confines the diversity of sonic textures and expressiveness, the configuration needed for each therapeutic exercise cripples the solution's accessibility and the high-end equipment necessary for the prototype execution is quite high-priced.

3. Approach

From all of the exposed approaches one predicament is prevalent, obstructing the distribution to the intended users: every solution requires specialized hardware to function and complex configurations to set-up. The authors were able to surpass obstacles and generate proof-of-concept prototypes, carving the path for musical therapy in Gerontechnology, however simplicity and autonomy are a must in order to expose and explore the benefits of music in senior citizens. We define a computational system, focused for the elderly, to allow musical expressiveness through motion, solely using the resources available in an ordinary home computer. Our goal is to achieve a scalable and confined solution, remodeling and adapting existent technologies so users can easily startup and use the proposed system to take advantage of the implied therapeutic benefits, which can recognize motion, translate it to an audio signal and reproduce the audio, with low latency.

3.1. Methodology

Our proposal relies on standard technologies in musical production to accomplish our goals: MIDI is a widely used standard to represent musical events, such as note or parameter variations, and Virtual Studio Technology (VST) [31] is a standard for software audio synthesizer instruments and audio effect plug-ins. With the VST technology, it is possible to dynamically incorporate advanced studio software components with professional audio quality into an application. Therefore, we envisioned our solution composed of a VST host application, capable of serial chaining multiple VST audio units considered as links, defining a straightforward flow for MIDI events and audio signals between links. There is a wide array of available VST plug-ins, which can improve the sonic capabilities and musical assistance of the chain, where each plug-in unit is responsible for fulfilling a specific task. The result is a very simple and specific modular audio application, focused on user accessibility, that can adapt by changing a link in the chain. The plug-in chain has three major constraints: there can be one or more linked MIDI VST plug-ins; followed by a single VST instrument (VSTi) plug-in; followed by zero or more linked audio VST plug-ins.

Our methodology is described as the following: the user interacts with their computer’s camera, which captures frames at a specified rate; these images are fed into a motion recognition component, that uses CV techniques to detect the user’s movements, extracting the motion data; the data is then passed onto a motion interpretation component, that is responsible for translating the motion data into MIDI message events, which in return are sent to a VSTi, capable of generating an audio signal based on MIDI events; the resulting audio is delegated to the computer’s sound system, and reproduced to the user, thus completing the cycle. Therefore, the user’s movements are captured, generating audio which is played back to the user, which responds with more movement, in a feedback loop.

In a detailed analysis, the solution requires some parallelism and extra components to function as intended, as shown in the component architecture in Figure 1. We defined a MIDI event pool to receive and send MIDI messages to the next link in the chain and a sound engine to handle the audio stream operations between audio components. The sound engine needs to have a single high priority thread to continuously reproduce audio, where speed and optimization are required in order to achieve low latency, hence simpler chains and processing effects will have impact on the speed and steadiness of the solution. The figure exposes the chain concept, showing the data flow and processing from the video capture device to the audio reproduction device.

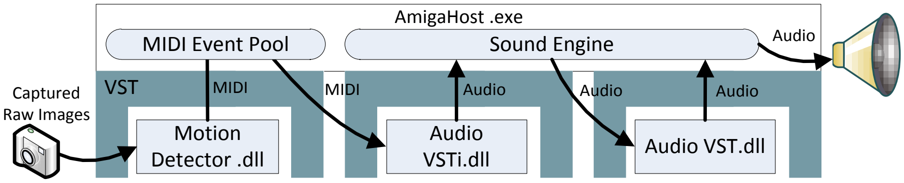

Figure 1: AMIGA component architecture. Image frames are captured by a motion detection VST, generating and sending MIDI messages to the host; the messages are forwarded to the next link in the chain until they reach an audio generating VSTi, which generates the audio signal; the audio signal is sent to the sound engine and passed to the next link, until the end of the chain; the resulting audio stream is sent to the audio reproduction device.

To initiate the process one must load the host console application with a configuration file defining the chain, which would start-off immediately processing our expressed methodology. The plug-ins are independent Dynamic-Link Libraries (DLL), that are encapsulated into the host via the VST wrapper interface, and can be swapped to create different chains, with a different configuration file. To terminate, the host should receive a kill signal. This methodology eases integration with other accessible-like applications at a process level and allows the design of an interface wrapper for further user control.

3.2. Computer Vision

We specify that the chain starts with a custom MIDI VST plug-in, responsible for capturing video from the camera, detecting the motion in the video stream and generating the MIDI events based on the motion data. These MIDI messages range from common events, such as note-on, note-off, velocity change, and stereo panorama, to unusual and specific events, like filter cutoff frequency changes or virtually any parameter available on the VST instrument. This VST should have its own processing thread for recognizing the user's motion, converting the motion into MIDI events and sending the events to the host, with a fast response time. This last requirement is necessary, so the user feels he is in control of the instrument.

To detect motion we focus on CV techniques, thus allowing some type of motion recognition with a common webcam. Advanced motion detection technology could be useful for a more complex and accurate gesture mapping, although to maintain simplicity it is preferred to release the dependence of costly hardware, resulting in higher modularity at the cost of accuracy. In order to detect motion, we developed the procedure detailed in algorithm 1, which allows detecting variations in successive frames with a fast adaptation of variable backgrounds. This procedure is faulty in eliminating background disturbances, however since normal usage is indoors, the noise is at the minimum, and with a sensitivity threshold parameter it is possible to smear out irregularities.

```
previousFrame ← CaptureAndProcessFrame();
loop
    currentFrame ← CaptureAndProcessFrame();
    motionData ← Difference(previousFrame, currentFrame, sensitivityThreshold);
    midiEvents ← TranslateMotionToMidi(motionData);
    SendEventsToHost(midiEvents);
    previousFrame ← currentFrame;
    Sleep(millisecondFrameRate);
end loop
```

Algorithm 1: Motion detection algorithm.

The frame processing procedure can be refined to optimize processing time. The procedure is needed to transform the frames to improve the results of the differential procedure, and converting each frame to gray scale and blurring it helps in the CV technique, although heavy image processing can result in higher latency. There is also a possibility of controlling the bottleneck created by our procedures by changing the frame rate. We suggest using a dynamical frame rate, with a maximum of 30 frames per second, adapting to the computer's current load. The resulting motion data is a black image with gray motion placed at the position it was detected, as shown in the central image in figure 2.

3.3. MIDI Mapping

As defined by the norm, MIDI messages are essentially composed of a static parameter identifier and the changed value, with 7-bit precision, therefore the motion must be translated into a range of [0–127]. To generate the MIDI events, we need to scan the image for gray spots and, according to each positive detections coordinates, generate the corresponding MIDI message. We suggest two different ways to identify motion, using either the Cartesian or the Polar coordinate systems, in the two dimensional field.

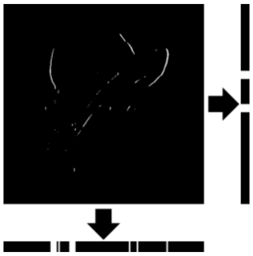

Figure 2: Motion detection result and image scale results. The central image contains the recognized motion in gray and the side and bottom images show the result of converting the central image to 1 by 128 pixels and 128 by 1 pixels, respectively

Using the Cartesian coordinate system, the simplest way of mapping MIDI is to scale the motion image with a simple interpolation methodology into two separate images, one with 1 by 128 pixels and another with 128 by 1 pixels. Using this procedure, the image is efficiently divided into each individual dimension, and each dimension can be associated with a specific parameter, as shown in figure 2. We suggest mapping the pitch of the played note to the vertical axis, with low pitches on the bottom of the image and high pitches on top, and the stereo panorama of each note mapped to the horizontal axis, placing each note to the left or right speaker. This gives the expressiveness a natural response, as the sound behaves in accordance to the position of the recognized movement.

Using the Polar coordinate system, each pixel's x and y coordinate must be converted into θ and ρ which, according to the Pythagorean Theorem, can be calculated using the formula presented in equation 1, considering the origin of both systems located at the bottom left corner of the image. These equations depend on computationally difficult operations, and are less recommended as it can increase the application CPU load. Nevertheless, the mapping of Polar coordinates can add to the dynamics of the solution, so it is worth exploring. In order to map the MIDI value scale, the image must be resized to a square of 90 by 90 pixels, so ρ does not exceed 128, and θ must be scaled as well, as it only ranges from 0 until $\pi / 2$. This methodology can be interesting to map parameters like the filter cutoff frequency or vibrato amount.

$$polar(x, y) = \begin{cases} \rho = \sqrt{x^2 + y^2} \\ \theta = \tan^{-1}(\frac{y}{x}) \end{cases} \tag{1}$$

We also suggest introducing knowledge by limiting the generated notes to a few octaves of certain musical scales, in order to create different musical environments and textures. The scales can be adjusted in real time, making the performance progress and, since note MIDI messages require two events, note on and note off, there should be a mechanism to turn off a generated note when motion in a certain area stops. This mechanism can also prevent the generation of consecutive "on" messages for the same note, as when a note is on, the only next state it can have is off, and vice versa.

4. Experiments and results

In order to evaluate our approach, we developed a prototype based on our proposed solution for the Windows operating system. Due to the specific needs of computational speed and low latency of the intended solution, we decided to implement the described approach with the C++ language which is closer to machine language and thus can be more efficient, albeit more prone to development errors. Nevertheless, the prototype remained faithful to the detailed proposal. It was developed as a console based VST host application, using the Juce library [32] as our sound engine mechanism, and a VST motion detector DLL, using the OpenCV library to implement the computer vision. The prototype presented the video stream from the video capture device, overlapped with detected motion in gray, in a maximized window, allowing changing specific parameters through static keyboard associations, such as musical scale, pitch and timbre of generated sound.

4.1. Test scenario

We piloted acceptance tests on our prototype, performed by eight senior citizens over sixty years of age, with the average age being that of eighty-three. The subjects had no previous musical experience or knowledge and had never been in direct contact with computers. Half the subjects had hearing and sight conditions: three showed some type of slight mental disabilities and one required the use of a wheelchair. The tests were executed in an isolated room, one subject at a time, sitting in front of a common laptop with an internal sound card and webcam. We used a 2.1 sound system, composed of a left and right speakers and a sub-woofer, to obtain an excellent and clear audio playback. Some examples of the prototype interface, generated output and test video capture can be found at http://www.dei.estg.ipleiria.pt/apereira/AMIGA_TestPhase1/

The evaluation procedure consisted of an initial interview regarding subject identification and musical background, followed by a simple explanation of the prototype functionalities. Each subject performed a ten-minute application run, starting with a simple sound and musical scale. There was a sound patch variation every two minutes, changing the sound timbre, and a natural progression of musical scales during the second half of the procedure. An observer, which monitored and recorded the experiment, finished each run with a brief questionnaire for the subject.

4.2. Analysis

The experiments were executed to evaluate the solution as a proof of concept and to attend on pertinent questions, so we conducted a trifold analysis to evaluate the solution: first, if it is capable; second, if it is autonomous; and third, if it triggers interest and motivation in elderly subjects.

For the first hypothesis, the prototype should allow the elderly to create music and sounds with our interaction methodology, thus being a fit Gerontechnology solution for musical expressiveness. To clarify this incognito we observed the test results, noticing seven out of eight subjects were able to execute the tests, using motion to produce music. The prototype performed flawlessly, however the failed test subject had major hearing and mobility deficiencies, constraining our proposal's overall effect. The experiment showed high levels of interest by the subjects, overpassing the common fear of technology in aged subjects.

For the second hypothesis, our approach focused on autonomy and independence and subsequently the prototype must correspond to the requirements. The application executed fluidly throughout the experiments, recording a latency of only 33.67 milliseconds and CPU peak usage of 5% without buffer overruns, without specialized equipment and sensory hardware. This demonstrates that, nowadays, an ordinary computer is more than capable of performing the approached methodology, exposing the potentialities of further investigation.

As for the third hypothesis, our motivation states upon providing a mechanism to approach the beneficial factors of musical therapy for elderly users. The test observations revealed that, although one subject was unable to perform the task, the remaining started with slow movements, building up excitement and moving with increasing dynamics. Moreover, albeit one specific subject stopped after six minutes due to the physical exhaustion, the remaining subjects switched members and movements to rest their arms, using their head or torso to make gestures. In the end, the ten-minute run time was not enough to sate the subjects' curiosity and leisure in the experiment.

The subjects were very intrigued, excited and happy to use our prototype, as observed in the dynamics of used movements and body expressions. They enjoyed the overall experience and were eager to participate in more experiments, insisting on the positive applications and benefits of our approach, such as a simple and fun excuse for physical exercise.

5. Conclusion

Shocking facts were revealed about the crescent impact of the elderly population in society, alluding to Gerontechnology to ease the problem and increase general quality of life of senior citizens. We focused on the specific subject of musical therapy and established the scientific effort carried out in investigating the beneficial effects of musical therapy with informational technologies, converging on the movement and expression capture mechanisms. The approaches were faulty in Gerontechnology, either by boycotting accessibility standards and constraining the replicability with complex and expensive solutions. Nevertheless, following Sapir's line of thought [25], there are still many paths to explore in creating musical instruments with unique and natural means of interaction.

Our proposed approach, focused for the elderly, defines an interactive musical environment allowing musical expressiveness through natural motions, using available resources in an ordinary personal computer, Computer Vision technology and current music standards. This methodology allows solution independence and autonomy from specialized and dispendious hardware, while delivering the beneficial factors of musical therapy to elderly and professionals alike. It is also designed to adapt and expand to future requirements, thus allowing the adoption and integration by researchers and developers.

We developed a prototype, faithful to our approach, and performed user acceptance tests to assess our solution with a group of elderly subjects, over sixty years old. The experiments disclosed promising results, with a high acceptance rate and flawless functionality, reinforcing the potential of Gerontechnology in musical therapy to contribute for the well-being and enhancement of life quality in the elderly population.

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