Virtual Interactive Space (VIS): Creating a Unique Dynamic HCI Ludic Engaging Design (Apparatus/Method) for Human Performance and (Re)Habilitation

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Abstract. This paper shares code that enables the making of a Virtual Interactive Space (VIS) where the *skin* of the invisible active sensor area is dynamically responsive to the velocity of a limb e.g. hand. Used in proprioception training of movement the patch is at the core of the author's *Reafferentation* concept, which takes advantage of human natural and unconscious capacity. The mapping of the patch to a sound (e.g. drum, thus realizing an 'air-drum') resulted in increased client engagement in physiotherapist-led movement training sessions. The paper also reflects on how a cable-less physical environment augments the research.

Keywords: Virtual interactive space · Performance art · Movement training · Rehabilitation · Motivation · Auditory · Multimedia feedback · Reafferentation

1 Introduction

Virtual Interactive Space (VIS) was first published in 1999 at the World Congress of Physical Therapy (WCPT) in Yokohama, Japan [1]. The VIS concept is subject of ongoing research focused on rehabilitation. Recently, adoption of such sensors and multimedia/games as responsive content in healthcare and rehabilitation has been more widespread and continues to grow. Importantly, the size of the game industry has resulted in affordable access to sensor-based game-control peripherals, which are used to source human input. Pervasiveness of sensor-rich smart phones adds to such accessibility to game and creative-expressive feedback to human gestures. The patch herein detailed illustrates such sensor-based opportunities to engage participants who are undergoing a movement treatment program as well session facilitators.

This paper first presents a background and overview of the research that resulted in the emergence of the patch and its use in rehabilitation. Following this introduction, the need for a wireless environment is stated to contextualize the intervention and end-users that have been involved in the studies. The patch is then presented within the graphical programming environment where it was created. This is cross-referenced to a compressed text format shared in the appendix, which enables others to copy and paste into the software. Specific results from the patch use are subject of prior publications

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where the patch was not detailed but rather acting as an aspect of the intervention as a whole. Thus, this paper focuses on the detailing of the patch within a rehabilitation context. Use of the bespoke system in performance (stage) and installation art (e.g. Museums of Modern Art), including the presented patch, is not detailed in this paper. However, for interested readers, HCI cross-informing learning that emerged from VIS system experimenting and improvising within the arts is presented in the author's prior publications e.g. [2–4].

1.1 Background

A focus of the VIS research has been on augmenting rehabilitation intervention via apparatus and method development. Bespoke systems that enabled exploration of human performance plasticity and digital media plasticity emerged. Closure of the afferent-efferent neural feedback loop where human gestures are mapped to multimedia to stimulate sequential gestures has been at the core of the work (biofeedback).

The mature body of work that realized VIS began around 1985 following explorative studies of the author having been born into an artistic family with members with profound impairment. Simple music mapped pedal-based weight adjusted systems were initially explored. The work included exploring commercial worn bio signal sensor systems, held and non-worn/held devices. Early research evidenced the need for a simple system where a participant could just enter a space and immediately begin manipulating media through unencumbered gesture. This was effective when compared to worn sensor systems where a preparation of a participant involved the application of conductive gel and precise positioning of sensors.

Bespoke hardware resulted in the form of a volumetric infrared sensing device developed for invisibly interfacing a human with a music synthesizer via MIDI communication (Musical Instrument Digital Interface). Later, as technology evolved, the human input data was mapped to computer software programs that enabled manipulation of multimedia (sounds, images, games, and robotic devices). The media selective opportunities of input (feed forward) and mapping (feedback) enabled the tailoring to individual preference, needs and desires, which was found to optimize participation of both client and facilitator.

The created adaptive VIS systems enabled motion data to be sourced and mapped to immediate and direct feedback stimuli that informs both the participant and observers (e.g. therapist, carer, and family). The concept thus empowers engaging, fun and playful interactions in interventions that are otherwise reported as boring and mundane where repeated movement exercises give no feedback to the participant (client/patient). As well as acting as an entertaining human performance instrument, the system can record the movement data for post-session analysis. The analysis informs of patient progress and the iterative design session-to-session within a program of treatment.

The dynamics of such motion activities involve proprioceptive and kinematic sensibilities. However, the early systems were lacking in translating that sense into dynamic feedback so that for example a high velocity movement gave a louder sound that a lower velocity movement. This was conceptualized as offering an interactive dynamic response to consciously driven movement in movement training. An analogy is in the physical world where a drum is struck with increased force whereby the drummer consciously desires a louder response/sound.

The detail of this patch is presented in Sect. 2. The next sections present the scope of the work as applied in the field, and, specifically, how latest advances in wireless technologies aid this work through addressing the need for a cable-less physical environment.

1.2 Wireless Environments – a Need and Recent Solution

The sensing space being infrared is beyond what the eye can register. However, such systems have historically necessitated the use of cables to transfer the data from the sensing apparatus to the computer or synthesizer. Typically, in this work, multiple sensing devices that constitute a testing setup usually surround a participant to source multidimensional input (e.g. left/right arm/hand, head, right/left leg/foot). The participant often would be wheelchair bound. In such physical environments, the cables were found to be a hindrance and often led to accidents or incidents of damage to cables and thus signal degradation or loss. Recent developments in data transfer efficiency and effectiveness include opportunities for building wireless systems in context of this research.

Stepping back for a moment and reflecting the history in the field of device-to-device communication, this body of work took advantage of the MIDI communication protocol shortly after it was introduced in the 1980s. MIDI opened the possibilities to connect various devices to other devices each with suitable MIDI input/output/through capabilities. In order to communicate, unscreened cables with male 5-pin din plugs on each end are typically used. For more robust signal transfer two 5-pin din to 3-pin XLR adapters are used to take advantage of screened, thus reduced noise, XLR cabling. Thus enabling increased distance design between sensors and robust signal i.e. reduced SNR (Signal to Noise Ratio). However, no matter robustness of signal, cables are rarely immune to abuse such as being rolled over by a fully laden wheelchair and/or the wear and tear imparted by incorrect system dismantling, wrongly winding of cables, and/or improper storage under weighted equipment.

Contemporary advances in hardware and software around 2006 resulted in wireless MIDI transfer systems – so cable-less communication became available and tested in this work. The system used was the M-Audio MidAir Wireless MIDI Transmitter and Receiver System. This was a 2.4 GHz wireless device that enabled interfacing MIDI hardware at distances up to 30 feet where a MIDI cable would connect a controller to a battery-powered transmitter. The transmitter sent the data to a receiver positioned adjacent to the system computer. The receiver with its USB computer connection functioned as a class-compliant cross-platform Windows XP and Mac OS X, 1 × 1 MIDI interface. In tests, this system exhibited limitations on data dropouts. Thus, it was not a true success and whilst offering wireless communication, data dropouts were found to confuse participants as feedback was interrupted with constant resets.

Latest computer and smart device system developments around 2014 include Mac OS Yosemite and Apple iOS that have opened the door for more robust and non-latency wireless MIDI communication over Bluetooth e.g. MIDI LE, a free app for iOS 8 that's designed to bring low-latency MIDI over Bluetooth LE to CoreMIDI compatible iOS-Synths and applications. If controllers are battery-powered in line with tablets (iPad etc.) the combination results in a clear space and no floor cabling to protect from wheelchairs. Testing is ongoing on the wireless system as of writing.

1.3 Emergent Modalities of Use from Created Apparatus and Methods

The scope of the research involves two modalities unique to the research apparatus and methods that have emerged and been investigated in the field. The first of these modalities of use is the means of extending the active range of sensor-emitted infrared light (IR) for the sourcing of motion data. This is where prism-based versus ball-based reflective materials were found from research to intensify the IR reflections back in the same direction as received [3]. In the case of the SoundScapes system IR sensors, the infrared emitter and receiver are mounted next to each other to take advantage of this. The method enables a typical 150 cm active IR range to be extended to approximately 14 meters, so a rough factor of 10x is possible with this material. Additionally, the material can be worn (as in MoCap system tracking); hand manipulated (data changed according to occlusion manipulation); or mounted (e.g. as a window blind) to enable whole body or limb occlusion to generate data e.g. for balance, kinematic, proprioception training sessions as an element of a physical dysfunction treatment program as reported in the author's previous publications [e.g. 1–5].

The second embodiment of IR sensor investigation is the creation of a dynamic air patch as an element of the VIS and this is the focus of this contribution in the field of Human Computer Interaction. This is introduced in the next section.

2 Dynamic Air Patch

Around 1996 the original patch shared in this paper was created in the Opcode MAX software (Opcode is now Cycling74.com). MAX is a visual programming environment that is easily accessible and thus widely used for multimedia and music. It is modular, with most routines existing in the form of shared libraries. The MAX API (application programming interface) is a set of routines, protocols, and tools that enables third-party development of new routines (called "external objects"). Because of the API, it requires no line coding unless one wishes to create new objects that are not in the extensive and growing library. An analogy to the use of guitar pedals (as in the author's initial work) exemplifies how MAX enables an input (guitar) to be processed (e.g. distortion, delay, reverb circuitry) and delivered (e.g. via an amplifier and speakers). The player responds to the delivered sound with next input (Fig. 1).

The Max software has evolved over approximately twenty-five years and since Max 5 (version as of writing is Max 7) there has been a compressed text format that enables more effective and efficient sharing of patches. Thus, the MAX patch used to create dynamic air is shown in Fig. 2 with the appendix having the same patch as a shared compressed text format for interested readers to copy and reuse by copy-pasting within the MAX environment to realize the patch as shown in Fig. 2.

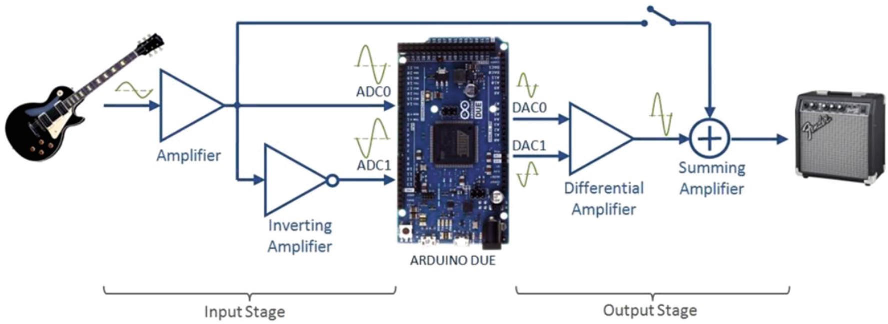

Fig. 1. Analogy of signal input, processing effect pedal (Arduino), delivery (amp) source http://www.electrosmash.com/pedalshield.

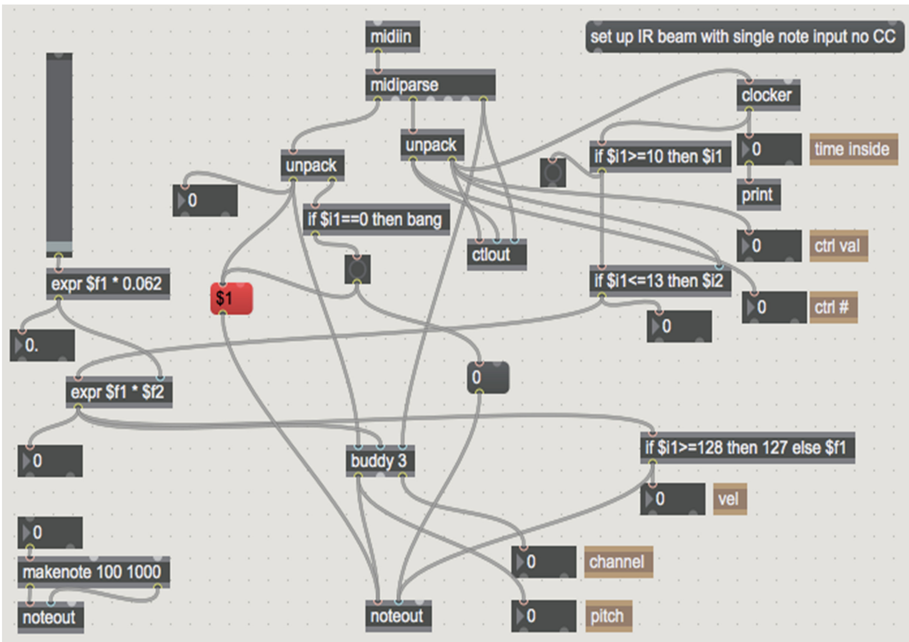

Fig. 2. Cycling74 Max 7 Dynamic Air Patch (see appendix for text code)

2.1 Patch and Use Detail

Knowing the attributes of MIDI the patch was created to use both discrete/binary and the continuous attributes of the MIDI protocol combined. Thus, a single note number corresponding to a musical pitch is programmed to an infrared sensor-activated free air space with a volumetric profile (VIS) (Fig. 3 – see also [3]). An interference velocity at the specified point in space (representing the volumetric 'skin') triggers this note such that the "Attack" attribute of the ASRD envelope (attack, sustain, release, decay) is

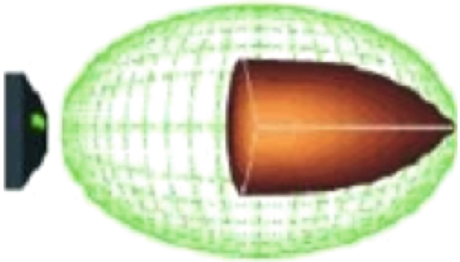

Fig. 3. Sensor with volumetric IR active zone – outer matrix green 'skin' illustrated Source: Interactive Light.

affected with 'aftertouch' active as an adjustable sensitivity expression attribute i.e. upper left slider in patch < expr > .

The patch contains test object sub-patch < makenote > to establish sound is generated and integer value attributes of MIDI controller < ctrl > value and number and time inside (e.g. when played by a hand). The other objects are self-explanatory with output to synthesizer via < noteout > .

The point in space corresponds to the location of a user such that kinematic coordinates and proprioception correlation matrix to achieve operation. Therapist goal and profile of the participant are crucial design factors of session system setup and presets.

Specifically in rehabilitation, the ability to program an invisible dynamic point in space offers opportunities for contemporary movement training e.g. increasing range of motion/reach. In this context, this gives opportunity for an intervention strategy using the human automatic response mechanism reafferentation [5]. Reafferentation gauges the relative success or failure of the Motor Act and initiates appropriate modifications [6]. In other words, a sequence of conscious reach for object location/object found or not found feedback (expected) and if not found initiate search sequential response that activates without conscious linkage.

Again using an analogy, if the reader imagines a glass positioned on a table within reach of a traditionally developed individual. Whilst initially viewing the scene, after a couple of reach and grab actions the participant is able to turn away and/or close the eyes and still be able to reach out as before and grab the glass – as targeted through kinetic and proprioception memory. If the glass is then moved a small increment further away by another person, the person reaching arrives at the memorized location and finding the glass not where it was expected there is an automatic response to search for the glass. Upon locating the glass in its new position, i.e. a little further away, the body sense is that its memory sensing was not accurate and a compensatory sensing mechanism activates to brain-body program the new location as the previous position. This relates to afferent-efferent neural feedback loop closure as previously presented in [7]. However, a big difference in this example is that the glass is a physical object and realistically any movement of the glass away from the reaching person will likely be detected. This makes the invisible sensing spaces (VIS) an ideal vehicle for Reafferentation due to the fact that each increment can be a pre-programmed preset that can be triggered without the participant knowing.

3 Proprioception and Kinesthetic Sense – Interoception and Exteroception

Simply put, proprioception is the sense of the relative position of the body, its constituent parts, and the related effort of movement. The brain senses the proprioceptive body position, its motion and acceleration. Kinesthetic sense is a related term referring to locomotion and physiological muscle sense, here including skin, joints, and structures such as tendons etc. Also related are the terms “interoception” and “exteroception” whereby these are in turn providing information about the internal organs, and the providing of information originating outside the body, via the eyes, ears, mouth, and skin. Central to proprioception are the body’s muscle spindles that inform of limb position and movement, so for example in reaching as outlined in the reafferentation example earlier introduced in this paper. In line with this, therapist experts have evaluated hand-eye coordination outcomes from the studies as a key improvement for participants with profound impairment(s).

4 Conclusions

This paper has presented emergent modalities from the author’s mature body of research. The two foci herein align with emergent models for in-action and on-action intervention and evaluation in contemporary rehabilitation that are subject of the author’s previous publications [1–5, 7]. Additionally, the same system in the arts, specifically in stage performance and in realizing interactive installations and exhibitions at Museums of Modern Art, has proven to be an invaluable learning vehicle for the author in applying the digital media system in rehabilitation.

Evaluations overall have been positive. This despite early doubts by institutes, therapists and carers to the introduction of interactive technology with profoundly disabled. Third party investigation is also generally positive, which includes a randomized intervention study reporting outcomes of the commercial product realized from the research showing a marked improvement of 400 % in training specific performance benefit [8]. Experts in the field – including occupational and physical therapists, neuropsychologists, psychologists - have positively evaluated outcomes from the studies over the years. However, this is the tip of the iceberg as increasingly new authoring tools to enable adaptation of systems more accessible for carers, family members and therapists to tailor for the person that they are attached to. More than ever the opportunities for motivated ludic engagement design for all abound. What is needed, according to these researches findings, is a funding infrastructure that enables specific classes and courses, as well as time to learn such ICT systems for therapists and others involved in the care system. In this way a contribution to future predictions of demographic health care service shortcomings, where there are increased aged where the incidences of impairment are highest, is made. Alongside, reflections on how such art-based performances contribute to opportunities in communication; possibly non-verbal and utilizing ICT should be considered beyond the traditional linear way of thinking when one considers assistive technology.

Future studies include a more thorough study of reafferentation via clinical analysis of joint position matching tests that measure a subject's ability to detect an externally imposed passive movement, as well as the ability to reposition limbs to predetermined positions without vision to guide. Through the apparatus and method presented herein, multimedia feedback offers a means to not only entertain and engage the participant and give data for the therapist, but also it acts as a direct feedback to retrain the proprioception and kinetic senses of the participant in instances of e.g. an acquired brain injury (e.g. stroke) where a sense of body-in-space is damaged (e.g. balance, gait, etc.) and intervention strategies use alternative processing to retrain.

A potential of the ongoing work are new ICT baselines for analysis and improved design of interventions that take advantage of sourcing information data from inside and outside a human and from the space surrounding that person, which is anticipated as cable-less and robust in signal to provide direct and immediate stimuli to human input.

Appendix

– Cycling74 Max compressed text (dynamic air patch)

<pre><code>
----------begin_max5_patcher----------
1544.3oc6a98bbZCDG+4y+UvP8Sct5QqD+rScmoSdpu1WyzICGHaqXN3FPmi
Syj+2KnErO6XDxmIJfievbb5.wpOZ0puZQ9KmrxcS4s7ZWme248NqV8kSVsR
UTaAq599J2sI2llmTqtL2s755jK4tqweSxuUpJulKc1uy4u+GmM7jsNeRHux
oVTbYN2onTxcDE61KaN04cuq+dK2Ky4R4m2wQCv004e69ocIxzqZt6OTwSk3
u5E4cFYsCKp8H0yW8A8Lxc2iHSYHka93uA98OiZ4myUUuaeIE62JJZdtplC8
9BQqQUJzV3WO4j1CqMjKE7O07j+Frz11apYWMsqvy7W63wTMHePWyxi0WOWT
VHKR1hsr+pRjjaXClcPETK9O0UBMOtmjCjigC62tgWMbW7ZG2MIEWpuqVgDV
XnBIDsHgNNR1kT0TtjW8AdQxFjNDyvE7bvEc5ba11bMWMrAHj1+HCBzKxKSj
sTEOYbr5QTii.HTKWA65pcLrqoE2TIuPWMJFNI1.WMxLxU6tKtZahpoDLcNe
2vy0DuxORgLluxMhFnCYr3WrWD46d.qmFBRw11IspEYbMvHvO.GLohdGDoEF
QKVXrqRTnaNr.hZjC3onAySKFBewX.9Aggz7xzq0L413gf6.UnxQAC5LHmBd
wbh9b3zDJ5IUVk6bSRtACbhTBdzqli4u.F3LAxd7Yn5OVv3SFw7V15d1rWJK
KFjWiOuMN3AX372j9iOIqXOy3JeeGX7KiOrfRYp.oZknwnK14SRuJonPqJCu
Hj.w3Z.XZAArbmXUzzxcGcQud3TpL8hsH+bDlziFd.SzGljFsvWd3zwq9gR5
4Uva7Jf3cPL3Q3U3a7pW7OJkaDd4+Fu54EtlwQ3E6Md4i4XnKgCivqWmoCTb
gyoB3OOGnQNxq3EMOzPGddM24zKfiKc58TEPczAZWAFEr6Z1goFc+w4.CI2o
B5w99GP03DEo.h1EuSIK1EuemuFoGXvKBX.t3rQ.FDuX8vRk45eCOrXFNAIp
aUqHdHZA7JddZNruXWR50C5qnxfH9gNuFFlQdPYwijhLvxoRbBinuYeV1mcX
ZmYT8mVVgJIXznwWjLDXWGK1Qvpgd2xmdjQffXbrF9ptXz1W+0f7wfDp0ZPo
k4kUX0qf+8GfCp3IM1dWoat7BQdt54+gdB3dYURlfeex4O7hTGgNTflIDwBh
aOgxHQgAOzn+l6k12NCh7W+nOzdi82GMlzzGzdOLRbDwCOqoHX3JHocOCnfT
H4Nhb3ErqpbWYkTTVnBfcFK9opk8xx6Xi5xBi+AjlRZLJuJNZ7zTB1OMkCMf
ibbi25lniFBFLditXUHM9d5fgqsqOEUZ2TG.rXmwGkJd94cJEUiFNJGGZ.JU

L.EJA5mIir.jJNAq6E5fBthW8q6M9U4xdmFEkTDc.tfW8JJiVrBJ2JxDMcw0
7wkTt9Anas4RywnZXzcfn0gzxJyCmVPJJz5zY.jvsoX2tKZ.FE7yQbrtcyW2
hTz503+pLLF+1cUsIpy4WaNdjYeJxSIlBywdjV2Ju4uvp5bQlN2JsoOOtkDA
j6ETCdCnnlNgNMe2TSdf2QSyHf9RnBknjLDqeyQ+iKrixbbyEEOdOmqZQsk+
P9UWtuJsu82M+ry8MpLdsTTjzuTv2emVnCtlqDYY7hC6vyD0s9.YCKFdJsl1
7tLmLGOqZNvXlCwZlSnAzIxpVSvXvo0bnVybniYNgyK5DXM5DXfqi8fS6+xC
iZNs6eeaYOfI1Cyt1CXh8.1wdL.O91iNFXMTXVYNpQ51ouhYxPcp87kMxd.6
o34QM8m1dX1KVH0jXOT57xd.vZ9yThIwlsGdLwbXVzdLo2xZVyiFGO.cXyK6
gZOE7JAniMwNKvt1yn7IbdwGp+LydHVKXnQ8WPjcsGvD6wR8WFI9wx1yXqJk
FLu3CXw4K7lY1Cadk.JyrG6INDnyKwgfIpw.Kp2vDspj4k4bjcVXhvS1s6Fd
UcWUpLD2sIeD2+TgqUeUTfeUUitU7aD8WuJK7tIUoWIj7T49JLi82FguWQ2s
kY7ph8htjv27j+5I+OPWCnOO
-----------end_max5_patcher-----------
</code></pre>

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