Customization of gaming technology and prototyping of rehabilitation applications

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ABSTRACT

The field of rehabilitation has recently seen various experimentations with games using interfaces that require physical activity. In order to establish the basis for developments and experimentations with those interactive systems, we propose a rapid prototyping approach using various commercial devices and open source software. To demonstrate this idea, we first show how a simple free game can be adapted to specific needs—for training or use by handicapped people— by using different sensors and control modes. Similarly, we show that an open on-line virtual worlds like Second Life, although not perfect, offers sufficient conditions for quickly building custom content and testing with usual interactive devices sold for handicapped. When presented to these prototyping possibilities, people from the target group (health care professionals, patients, handicapped, families) are able to relate to their needs and to elaborate on the use of such systems. In other words, the availability of a simple prototyping platform with free games and new interfaces already opens the discussion on the design of original rehabilitation applications.

1. INTRODUCTION

An increasing trend in gaming is the use of interfaces that require physical activity for an optimal user experience (e.g. the Sony EyeToy[1] or the Nintendo Wii[2]). These and other similar sensor-based interfaces offer new opportunities for players to interact with a game so as to become more engaged. Previously, such interaction were mostly restricted within the domains of virtual reality research (e.g. Vivid's Mandala system; Vincent 1993) or professional arcade games (e.g. the famous light guns, Meyer et al. (1979), Bartels et al. (2004)). Such gesture interaction technologies are not new; however, their recent availability as interface means within affordable mass-market gaming products can be seen as evidence of a broadening usage beyond solely entertainment.

Marginal application areas for games, such as within the field of rehabilitation, challenge the use of such interactive interfaces from various perspectives. To mention only few possibilities, Rand et al.(2004) have shown that the Sony EyeToy can replace Vivid GX for stroke rehabilitation, or, as mentioned by Ijsselsteijn et al.(2007), the Nintendo Wii Bowling can keep elderly people fit in retirement homes. However, if using console games 'as-is' in a different application context is interesting as a proof of concept, this also usually outlines the limitations of the commercial products and their inadequacy to the specific needs. Adaptability to each specific user and evaluation of use are two examples of what needs to be improved.

We have encountered the limitations of console or PC game for rehabilitation in many cases. For instance, we were recently in contact with a family willing to provide their severely motor handicapped son with the possibility to play computer games. What they found commercially available are two large push buttons that are positioned on each side of their son's head. The buttons are plugged into a PC so that head movement replicate joystick controls. When observing him play a motorcycle simulation game, a mis-match

1 http://www.eyetoy.com, *accessed in March 2008.*
2 http://wii.com/, *accessed in March 2008.*

was evident between this interface and his limited motoric skills; in other words there was no way for him to drive the vehicle efficiently. What results is a poor gaming experience and frustration. This experience strengthened our belief that it is possible to design and develop a better interactive systems for such a person. We targeted various sensors to be tested, a dedicated program could be made so as to offer the possibility to tune the interface parameter controls and to choose an adapted content. Such a (perfect) mix 'n' match solution does not exist, as normally, to create such a product requires industry intervention due to the engineering and support affordable only to a commercial company. But this leads us back to the original problem: commercially profitable solutions are made for the mass, and do not fit special needs...

This experience echoes a former experiment by Brooks and Peterson (2005) who used a video game platform room that was accessed by children in a day-care ward at a number of international hospitals. Among other conclusions, the study demonstrated that the Eye-Toy game adaptation was limited such that both interface and content could have been improved to address the children's different abilities. When approached about a research project to address these needs in the field, the industrial partners stated their desire, as a commercial company, to not be associated to disabled children as they feared being seen as exploiting them. This example shows that, despite the reality of the needs and the potential markets of the increasing aged and disabled in society, another approach shall be found to progress in this area.

What we suggest to shift the focus of the problem from a product design matter to a focused prototyping opportunity, where custom devices and software can be tested for a specific user. Providing people having a specific need for rehabilitation (patients or therapists) with the ability to test new technologies is the primary requirement for the design and emergence of innovative tools. More specifically, application prototypes are very efficient communication supports in the collaboration between experts (patients/families and/or therapists) and the technological experts (developers and/or researchers). This is precisely what the current gaming interfaces and the open source software community can provide; affordable access to an increasingly large range of devices, and the possibility to freely use and customize software with various levels of technical skills required.

In order to demonstrate this, we build interactive systems with free open source games — namely Planet Penguin Racer[3] or Neverball[4] for instance — and various interaction devices — web-cam, Soundbeam[5], Wii controllers, compass sensors, etc. We have originally been using these systems as demonstrations for medical or pedagogical professionals to show how the technology can be adapted. What we experienced is that, from their point of view, these systems are perceived as potential applications, and this despite the technological simplicity and the use of pre-existing software.

This paper shows how prototyping of rehabilitation systems can be done in practice, first by comparing different devices and control modes for one game, and second by quickly prototyping a game adapted to one device and a specific control mode. We will then present the feedback we have had when using this approach and discuss the problems still to be resolved.

2. HARDWARE PROTOTYPING

The principle of our approach is to take existing games and to swap the usual keyboard and mouse interaction paradigm with more physically involving interfaces. This is done by modifying a game which source is available, and by integrating the code for reading the input from other devices.

2.1 Testing platform

In this experiment focused upon to exemplify our approach, we used the game Planet Penguin Racer[6] (PPRacer), an open source project sufficiently established and advanced to offer good quality graphics, sound and game-play. This is a racing game where the user controls a penguin descending a snow-covered mountain route. The challenge is for the player to maximize his or her score by targeting herrings that are strategically placed along the way, while missing trees and arriving at the end of the route in the shortest time possible. The thrill of playing comes from the feeling of speed, the risk of hitting obstacles, and the possibility to jump to save time.

3 http://developer.berlios.de/projects/ppracer/, *accessed in March 2008.*
4 http://icculus.org/neverball/, *accessed in March 2008.*
5 http://www.soundbeam.co.uk/, *accessed in March 2008.*
6 http://developer.berlios.de/projects/ppracer/, *accessed March 2008*. PPRacer is a branched version of TuxRacer with minor changes and improvements.

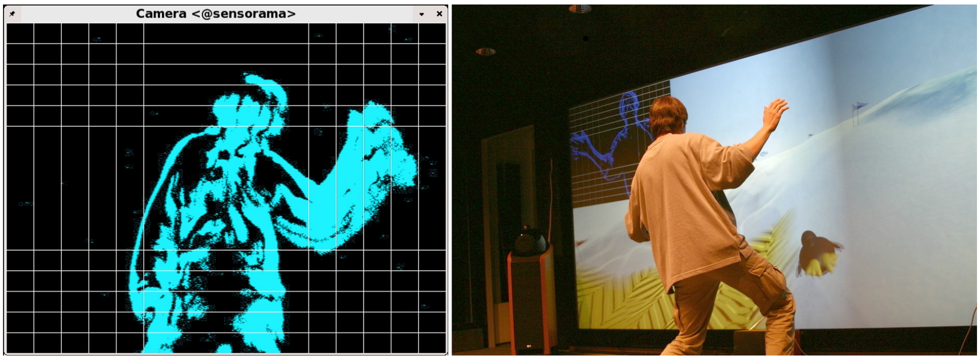

Figure 1: *The camera motion tracking grid — a player steering the penguin with body movements*

The three devices we used for controlling the penguin were: a camera, a SoundBeam ultrasonic distance sensor, and three-axis accelerometers (same electronics what Wii controllers have). Here is how each interface works and which steering paradigms are possible.

2.2 Camera interface

In the case of the camera device, motion is detected by frame subtraction. The steering direction and intensity are computed according to the amount of movement detected in the left and right quadrants of the camera field of view. The central area is neutral. In addition, acceleration and braking can be computed similarly from activity detected at the top and bottom of the image respectively. Processing of the camera image is via the Open Computer Vision Library[7].

The user is positioned in front of the camera which, in our case, was positioned under the screen facing the player so that movement on either side is used to steer the penguin. Players can wave one or both hand(s), lean on one side, make a step in either direction, or otherwise control via selected gesture. A repositioning of the camera can enable a level of head control. Figure 1 shows a player in action and the motion detection grid.

Figure 2: *The soundbeam device – a player steering the penguin with head movements.*

2.3 Ultrasonic sensor interface

The SoundBeam is a commonly used device at special schools and institutes. It is used mostly for making music by gesture ("piano" keyboard in the air). We adapt it in our work into a game interface. The sensor device measures the distance between the ultrasonic emitter-receiver and an obstacle reflecting the narrow beam. In this case, the distance measured by the device is only used to steer left and right.

Considering a calibrated measurement range (e.g. [0:50] cm), the center corresponds to the neutral position (e.g. 25cm), a shorter distance steers in one way (e.g. [0:25] cm with device on the right steers to the right) and a longer distance steers in the other way (e.g. [25:50]). The best way to use this interface is to sit in a chair and to turn and lean the head to the side (with the device pointing at the head). With full body movements, the user often moves out of the rather narrow beam and loses control.

7 http://sourceforge.net/projects/opencvlibrary/, accessed March 2008.

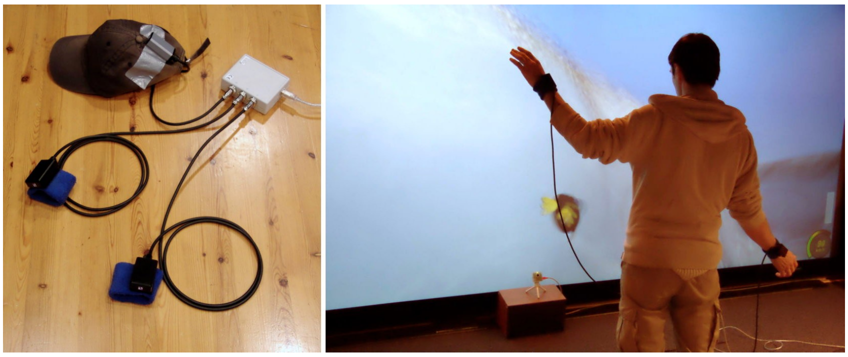

Figure 3: *The three accelerometers – a player steering the penguin with arms movements.*

2.4 Acceleration sensors interface

For the third interaction paradigm of our study we focus on accelerometer sensors[8] – they are cheap and easily interfaced with electronics controller to communicate with the PC, through USB or other connector. Using these sensors, we measure the orientation of the accelerometers relative to the vertical direction (gravity). They are placed and fastened on the wrists of the player. The two resulting deflection angles are then used to detect the orientation of the arms.

Mapping of the sensor data enables steering gestures such as: the neutral posture (penguin glides straight ahead) is with the forearms almost horizontal, lowering a single arm means touching the ground and therefore initiates braking on the side of 'contact' (similar to rowing a boat). Lowering both arms acts as a brake, and raising both arms accelerates the penguin's descent. A short calibration also allows to consider a comfortable posture for the user as being the neutral posture.

3. SOFTWARE PROTOTYPING

While attempting to develop interactive systems for use in rehabilitation, we have encountered several major issues:

- Each and every case is different. Every user has different needs and different capabilities and the software & content need to be extensively customized every time.
- The customization has to be done quickly, ideally directly on the spot, in response to the immediate actions of the user or therapeutic needs. This is important especially when trying to find out what kind of activity is appealing to the user, because it is often difficult for these people to travel and/or endure multiple trial sessions.
- Ideally, the content customization should be doable by a person without specialized skills, perhaps after a short training. Most software used in this context is either not customizable at all, or requires specialized skills and software, for example game engines re-purposed for rehabilitation applications – Robillard et al (2003), Rizzo et al (2006) – to adapt the functionality.
- Communication between the users (both therapists and their patients) and the engineers providing support is difficult – it is often easier to show how the idea should work than to describe it to the other side, but that requires that the content is user-modifiable.

All these issues give raise to the need for a perhaps incomplete, but simple and readily available prototyping and testing platform. In order to satisfy this need and to demonstrate the possibilities available in the off-the-shelf free software, we are proposing a rapid prototyping approach using the Second Life® virtual world developed and maintained by Linden Lab[9] since 1999.

3.1 Testing platform

Second Life virtual environment is an online persistent world, with the users connecting to it using specialized software (client). This software is a free download, with the source code available as well. The key difference from other similar applications that enables us to use Second Life as a prototyping and testing platform is the fact that the entire virtual world is user-built with simple tools provided directly inside of the user's client. Non-interactive content can be built literally by clicking and dragging the mouse, interactive

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8 Nintendo Wii controllers could provide similar result as they include accelerometers too.

9 http://lindenlab.com/, http://secondlife.com/, *accessed in June 2008.*

Figure 4: *Examples of possible activities in Second Life -- navigation by flying, riding a jetski, car racing.*

content can be obtained using the built-in LSL scripting language. Furthermore, a lot of pre-made material can be obtained easily either for free or for modest payment.

On the other hand, Second Life has also few significant technical shortcomings, limiting its usefulness mostly to the prototyping and situations where a tightly controlled environment is not absolutely necessary and occasional technical glitches are tolerable. Most of the problems stem from the fact that the system is a massively multi-user application, with tens of thousands of people being simultaneously online at any given moment. The other users can teleport from place to place, engage user's avatar in conversation or even attack it at any given moment, potentially disturbing the session. The system also suffers from chronic performance and scalability problems, especially during peak usage times, resulting in frequent outages.

Finally, there are also therapeutic issues with virtual worlds, such as users trained to perform certain tasks in the virtual environment may not necessarily be able to transfer the acquired skills to the real world or users performing significantly differently in the virtual environment due to the effect of anonymity/"mask" provided by the avatar. These issues are not specific to Second Life, though – similar problems face the users of any online multiplayer games when repurposed for the rehabilitation/therapy needs. A good analysis of these issues can be found in in Gaggioli et al (2007). Any attempt to use virtual environments for such purposes will have to take these into account.

The two following sections present two examples how content can be easily adapted and prototyped within Second Life. These examples were developed to with the boy from the introduction in mind – severe motoricity handicap, spastic, confined to the wheelchair and using Joybox – a simple assistive device consisting of several buttons and switches acting as a joystick – to interact with a computer. The objective was not to provide therapy as such, but to enable a form of entertainment and an environment to exercise both his cognitive and motoric skills. The setup has still to be tested with the child.

3.2 Avatar navigation and vehicle driving

The first simple scenario is an attempt to get the user familiar with the controls and basic navigation in the environment. One popular way how to explore the virtual world is to fly. In this case, we have used an island with a lot of interesting things for a child to explore and have set up the controls in a way that allow the steering of the flying avatar (figure 4 left). The main issue with this task is that full control of the flying avatar requires at least 3 degrees of freedom (turn left/right, move forward/backward, climb/descend), necessitating 6 buttons or a regular gamepad to use. As such, it is not a very practical application.

In order to constrain the number of degrees of freedom required, we have got inspired by a racing game that comes with the Joybox device. The boy had major problems controlling that game, because it was too difficult first and second the controls didn't map too well to the binary on/off nature of the switches of the Joybox. Second Life allows building all kinds of vehicles and driving them is a popular activity. We have adapted some of them to the limited controls provided by the Joybox device. In order to keep the things simple, we have constrained the controls and used only two switches for lateral steering, without brakes and throttle, letting the vehicle move forward at a constant speed on its own. The boy is used to two buttons, either as two large push buttons on the table or two head switches attached to his wheelchair, so this control arrangement shouldn't pose a large problem for him. The arrangement is shown in figure 4 centre and right, with the avatar riding a jetski and racing a car.

Figure 5: *Example of content customization – building a simple obstacle course*

3.3 Content customization

The scenario described in the previous section allows wide options for adaptation, depending on the needs, skill and interest of the user. For example, the driving can be made easier or more difficult by swapping the vehicle for another one, with different characteristics (such as a scooter for a sports car). Obstacles, such as traffic cones or boxes can be easily added or removed or the track redesigned. Competitive racing with family, friends or other users in the same virtual environment is possible without any extra effort. All this can be done by a non-technical user after a short demonstration – parents, helpers, therapists.

Figure 5 shows the process of constructing a simple obstacle course for a motorbike using the built-in tools. In the left image the user is show constructing a simple traffic cone out of two pieces – a flat and square stand and a conical top. These traffic cones are then placed in the environment for the user to drive through (right sub-figure). The built-in tools are quite primitive, but a lot can be built in short time with little effort – a valuable feature for building quick prototypes for testing various approaches or to adapt the environment on the fly, depending on the immediate needs.

4. DISCUSSION

We have been intensively presenting our games to a broad public, both in our laboratory facilities and at some exhibition places. We tried to experiment with handicapped persons as often as we could to get a better knowledge on the adaptability of our approach, and to learn what should be the next development step. Here is a synthesis of observations and feedback we obtained.

4.1 Tests and limitations with our prototypes

The learning curve to play the penguin game is negligible and this was evident by people's responses who often upon achieving an easy level would ask to play a level more in line with their skill level. Compared to the camera interface, the accelerometer based system offers an increased intuitiveness in control due to a decreased latency in the control and the ability to break (and thus make sharper turns). However, the camera does not require to wear anything and avoids the cables which can be somewhat encumbering. A wireless version of the accelerometer device or the use of Wii controllers (same technology, but to be hold in the hand instead of placed on the wrist) could offer a good compromise.

In a further experiment, we tested the ultrasonic Soundbeam device with a profoundly disabled young adult controlling via head movement. She played the game in front of a 5 meter wide by 2 meter high back projection screen. Although she was unable to speak, her two helpers interpreted that her communication was of being very excited and happy at having fun. She continued playing until exhausted. The device is hard to setup precisely though, as it only detects movements along an invisible line in space (the player may accidentally get out of the line). Comparatively, the camera is easier to adjust according to each person's disposition (e.g. wheelchair) and preference (whole body movements, limb, or head). The visual feedback from the camera field-of-view is essential in guiding us to position the person optimally in the neutral zone before starting.

Development wise, the examples presented for hardware prototyping did require little but expert programming. This is equivalent to what we ask to our Bachelor students in C / C++ programming projects. Regarding electronics, only our home made solution for the accelerometers required a bit of engineering, and those can be replaced with Wii controllers without problem. The software prototyping presented is, as stated, approachable to any computer users, but more can be done with computer science experts.

Figure 6: *REHAB Scandinavia 2007 and 2008; steering the penguin when exercising on a fitness ball.*

4.2 Feedback from presentations at Scandinavian Rehab Messe 2007 and 2008

To get an initial feedback on the approach from rehabilitation professionals, we presented the concept at the REHAB Scandinavia in 2007 and 2008 — an international Messe event presenting products from the Scandinavian health care and rehabilitation market that is held annually in Denmark. Our stand was set up for live demonstrations of games, including our adapted PPRacer with camera interface.

Attendees at our stand ranged across the spectrum from potential users including therapists and associated medical experts, disabled people and their family/friends, to those in associated industries, i.e. commercial distributors, related educations and national/international representatives of organizations. The community of potential end users that tested the system, i.e. the people with impairments, physiotherapists and occupational therapists, were especially interested in the adaptability of the system. The commercial entities observed the system in use rather than tried it themselves, but their response was also positive and word of mouth was such that, during the last two days of the three day Messe, people were arriving to try the system telling us that others had told them of it. We also noticed people returning to try it so as to beat a previous score. These 'players' also exhibited a sense of self-esteem as they performed for the public.

Unanimous positive feedback was received. The line of people waiting to try the system was in itself an indication at the potentials of the concept. Many people after testing or observing the interactive system asked us if they could purchase it, however, as it is a research prototype this was not possible.

It was also observed that the therapists would often test the game and then communicate to their colleagues who were observing of how it would suit to be used for a certain person in their care. This selective referencing to people with impairments at their institute was interesting as they visualised that person in the game scenario and placed themselves into that role, in line with the precept out of the Chicago school of sociology and specifically the work of Robert Park.

Following some of these comments, we borrowed one of these large exercise ball commonly used in physiotherapy to experiment with the camera control of the penguin game. To control the Penguin by sitting on the ball required lateral and frontal movements of the lower back, waist and hip region, whilst simultaneously keeping balance with the feet on the ground. The size of the ball fitted the size of the large screen feedback well as the player could range from maximum left-to-right through a movement of the feet (from heel-to-toe or vice versa) that corresponded to the flexion of the seated area. The upper torso could be static or more active. Generally speaking each person exhibited different characteristics of 'naturally interacting' – with the ball (i.e. that which mediated control of the game) – and the penguin (i.e. the controlled artefact which in turn through the mapping strategies was mediating the responsive movement of the player).

This natural, or intuitive interaction, is achievable (and arguably optimal) when the player is unencumbered, i.e. no attachments or held device required so as to be able to move freely. This autonomous efferent response (feed-forward) to afferent stimulus (feedback) was quickly identified in most players, even in such a short demonstration framework. Flow state, as defined by Csíkszentmihályi (1990), and ludic engagement were also suggested by observers. Many of the physiotherapists excitedly speculated to us of benefits such as eye-to-hand coordination, balance training, proprioception training, general lower-upper limb coordination, and more.

5. CONCLUSION

The examples presented in this paper typify our approach towards a targeting of optimal player experience through adapting interface or content to match needs, preferences and abilities. It also illustrates how we have attempted to approach one of the current problems that we see between the commercial gaming solutions and the specific needs for rehabilitation training or people with disability.

We can conclude that such an approach of taking existing software and hardware technologies as a foundation for a cross-disciplinary user-centred design of dedicated applications can provide professionals and educators with new opportunities in rehabilitation. Software and hardware prototyping can be greatly reduced by adapting off-the-shelf open source solutions to a therapeutic need. Our approach has exhibited opportunities that can evolve if an effort is taken to open spaces for dialogue between the various associated disciplines. Such opportunities and methods of use have to be disseminated and made available to society.

The confrontation of various interaction devices and paradigms for gaming situation should also develop therapists' awareness to the possibilities of new technologies, and hopefully raise new ideas of scenarios for psychotherapeutic training, eventually leading to a fully custom solution once the needs and requirements are clear.

The creation of libraries of adaptable input devices alongside adaptable content would be optimal to suit preferences, desires, as well as the physiological or psychological profiles. If realised, such an open platform could become an evolving vehicle for openly sharing interdisciplinary and multidisciplinary knowledge alongside user/expert experiences with easy (authorised) access for use. Such a platform could be centralised with on-line real-time interaction as a distinct possibility.

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