Swimming Across the Pacific: A Virtual Swimming Interface Proposal for SIGGRAPH 2004 Emerging Technology

Tzu-Pei Grace Chen*, Yuichiro Kinoshita, Yasufumi Takama, Sidney Fels, Kenji Funahashi†2 and Ashley Gadd
Human Communication Technologies Laboratory
Department of Electrical and Computer Engineering
University of British Columbia
rm155A – 2356 Main Mall, Vancouver, BC, Canada, V6T 1Z4
+604 822 4583
http://hct.ece.ubc.ca

[2] Center for Information and Media Studies,
Nagoya Institute of Technology
Gokiso-cho, showa-ku, Nagoya 466-8555 JAPAN,
+81 52 735 5528

Abstract

As a locomotion interface for virtual reality, swimming afloat in water, is an unfamiliar and intriguing paradigm. We propose to bring our virtual swimming apparatus to SIGGRAPH 2004 Emerging Technology. In our exhibit, we will showcase the swimming apparatus and the virtual ocean environment. The swimming participant will be suspended in the apparatus, an 8ft cubic frame mounted with pulleys and cords, in a prone position via a hang-gliding harness. He or she will see the accompanying graphic system which renders sky, sea waves (including splashes), ocean floor and a virtual swimmer. The virtual swimmer mimics the user's swimming movements by processing sensor data, while the head-mounted display supplies the virtual view. Preliminary user experiences suggest the system is capable of providing realistic swimming sensations, and that it has great potential as a general purpose navigation system in immersive environments. The compelling SAP experience attracts attention from artists, scientists and other researchers around the world, both as a performance art piece and a virtual navigation prototype. We would like to provide the same experience to SIGGRAPH attendees, enabling them to swim in mid-air and feel as if they are swimming afloat in water.

1 Introduction

Imagine floating in an environment where the sun shines, the sea is calm and the marine creatures are friendly. Starting in Los Angeles, your goal is to keep swimming forward until you have reached Tokyo. On your way there, you may encounter birds and fish who cheer you on for your noble attempt to cross the Pacific Ocean. Landmarks and beacons sometimes appear to indicate your progress and encourage you to propel your body further so you can see more beautiful scenery. When you get tired, you can just stop. The ocean current still moves you forward as you float. There is no risk of drowning, sun burn, or shark attack. This is the kind of activity our virtual swimming interface aims to produce.

*tzupei, yuichiro, yasufumi, gadd, ssfels@ece.ubc.ca
†kenji@center.nitech.ac.jp

Swimming Across the Pacific (SAP) takes inspiration from the performance art piece "Swimming Across the Atlantic" (1982) [Misheff 1982]. It was performed by the artist, Alzek Misheff, who accomplished the artistic endeavour by swimming in the pool of the ocean liner, Queen Elizabeth II, traveling from South Hampton to New York. Over twenty years later, the next stage of this performance art is to reach an even higher goal by swimming across the Pacific, from Los Angeles to Tokyo, in an airplane. As one of our artistic goals, we plan to "swim across the Pacific" in a virtual swimming machine. To do this, we developed our virtual swimming locomotion interface. While this swimming machine is made for anyone to swim and enjoy the virtual water, it is also built so that it can be in an airplane so that we can do it in the air.

Figure 1: Swimmer in the SAP apparatus.

SAP provides an exciting and interesting swimming apparatus for the expert performer and the novice. The swimmer is suspended in a real swimming apparatus but navigates in a virtual Pacific Ocean environment. SIGGRAPH attendees have the opportunity to try out our newly developed, never before exhibited virtual swimming apparatus and enjoy the compelling experience of swimming mid-air in a virtual ocean. The apparatus, an 8ft x 8ft x 8ft wooden frame, may resemble a torture-chamber but it is actually very comfortable to be suspended in. The use of bungee cords adds buoyancy, while sand bags add resistance to the swimmer's kicking actions. Swimmers wear a minimal amount of equipments (a head-mounted display (with attached tracking sensor), a hang-gliding harness, wrists and ankle bands for securing sensors) such that he or she is hindered as little as possible during virtual swimming. The experience is fun even for non-athletes and hydrophobes because swimming actually takes place in a controlled air space, instead of in water. The SAP virtual swimming system provides cradle-like comfort for users while engaging them in the exciting virtual aquatic navigation.

2 Technical Innovations

Virtual reality has been demonstrated to be a powerful tool suited to many work-related applications in distance education, hands-on training, navigation, orientation, visualisation, and entertainment [Jones 1999; Durlach and Mavor 1994]. It permits users to experience and interact with synthetic worlds in a controlled environment, allowing safe experimentation in simulated, real-life situations. It provides an immersive experience through convincing visualisations and other sensations; experiencing these in a confined space makes it an invaluable tool of discovery.

"Locomotion interfaces" such as virtual walking, virtual hang-gliding and others, are closely tied to virtual reality. In an artificial reality, where the users have a presence in a 3-D space and use their bodies as natural input devices, development of locomotion interfaces is vital for immersive VR experiences. Hollerbach et al. defines in [Christensen et al. 2000]: "Locomotion interfaces are energy-extractive interfaces to virtual environments and fill needs that are not met by conventional position-tracking approaches or whole-body motion platforms". Researchers in VR, such as Durlach and Mavor, particularly advocate in [Durlach and Mavor 1994] the development of locomotion interfaces, because with their improvement come many more unforeseen applications.

Virtual swimming requires the implementation of a new locomotion interface, which introduces the possibility of new virtual reality applications. One unique aspect of our swimming system is that it occurs at the water's surface, requiring the simulation of the boundary between air and water. This is one of the key issues we address in our system. While we use our swimming apparatus to move in virtual water, it could be used more generally to move in data spaces that use liquid as a metaphor. A picture of a user in the SAP apparatus is shown in Figure 1. The accompanying images of the virtual environment (Figure 4 and Figure 5) resemble an ocean scene.

We have implemented dynamic waves and splash action (described below) so that both the participant and the viewer experience water like scenery as the participant moves. Our scenery is currently simplistic, however, it is a relatively straight forward effort to improve realism using caustics [Stam 1996], fog effects [Woo et al. 1999; Hill 2001] and texture[Woo et al. 1999; Hill 2001] to achieve a different representation of sea, sky, sun and a swimmer. This novel approach to exploration and navigation makes it an emerging technology.

2.1 Technical History

Previous locomotion interfaces have involved walking, bicycling and flying, but little has been implemented relating to swimming.

Sarcos Treadport [Christensen et al. 2000; Hollerbach et al. 2000] is a well-developed example of a walking interface. It comprises a large tilting treadmill placed in front of a CAVE-like visual display [Cruz-Neira et al. 1993]. The walker is attached by a mechanical tether that exerts appropriate force to the user's walking experience on a slope. The visual simulation depicts outdoor terrain. Footstep sounds are in the process of being developed for additional realism.

Bicycling interfaces include the Peloton Bicycling Simulator and Trike. The Peloton Bicycling Simulator [Carraro et al. 1998] includes a stationary bike, a computer, a fan and a sensor control unit. It provides users with visual and audio effects. Moreover, users feel pedaling resistance, bicycle tilt, and wind effects synchronised with their movements over the synthetic terrain of the virtual cycling course. The graphics were developed in VRML, allowing participants to join their friends in the virtual environment via the world wide web. Another bicycle example is a "rideable computer", called Trike [Allison et al. 2000]. It consists of a tricycle with an onboard computer. The visual display is derived from a head tracker on the rider and a potentiometer connected to the steering axis of the tricycle. The video output of the computer is fed to the cyclist's head-mounted display. The vehicle does not have to be stationary; in fact, it is thought that by combining the visual display with non-visual cues generated by real cycling, the subject is less likely to get motion sickness. The idea of generating one's path based on one's earlier positions is also a focus of Trike research.

High-end flight simulators have been used in the air force and pilot training schools for a long time. Their features often consist of a realistic visual display and a Stewart platform mount [Stewart 1965-1966]. Historically, flight simulators have been available either publically or commercially, usually for entertainment, such as Dreamality's DreamGlider, JetPack, and SkyExplorer, and the latest version of Ars Electronica's successful HumphreyII [Futurelab 2003] that includes some force-feedback. These systems include a head-mounted display or monitor for visual cues. Sound, wind, and movement also enrich the flying experience. Since these systems were built for entertainment, the visual displays are game-like: good flying performance scores points and poor flying results in point deduction. Another flight simulator of note simulates the flying experience from the passenger's point of view, rather than that of the pilot. Built to treat "fear of flying" [Hodges et al. 1996], this therapy is reported to have had some success with patients.

Examples of swimming interfaces include Fraunhofer's Aquacave (no longer publicly available), which allows virtual interaction with cartoon fish characters, and Virtual Diver [Buffa et al. 1995], which is used for artificial reef study. Both appear to be in the early stages of development. The Aquacave used a paragliding harness and a pulley system to suspend the diver in a CAVE, wherein a virtual underwater environment is displayed. The Virtual Diver explores methods of mapping photographs of artificial reefs onto a 3-D reef model, which is then explored using a 3-D joystick. There are also many high-end hardware and software systems that use virtual reality for undersea exploration; case studies of today's marine navigation and positioning technology may be found in [Jones 1999]. In all of the above examples, the focus is on the underwater environment itself, rather than on a locomotion interface based on surface swimming. Our locomotion interface is unique.

2.2 System Description

Our current design for the swimmer is comprised of a swimming apparatus and a virtual ocean environment. The swimmer wears eight Polhemus Fastrack sensors and a head-mounted display. The software links all the pieces together.

2.2.1 The Swimming Apparatus

The swimming apparatus (Figure 2) is an 8ft x 8ft x 8ft wooden box frame with horizontal beams on top and bottom. By running static cords through the pulleys mounted on the beams and attaching the cords to the harness with carabiners, the user is supported at the shoulders and hips in a prone position.

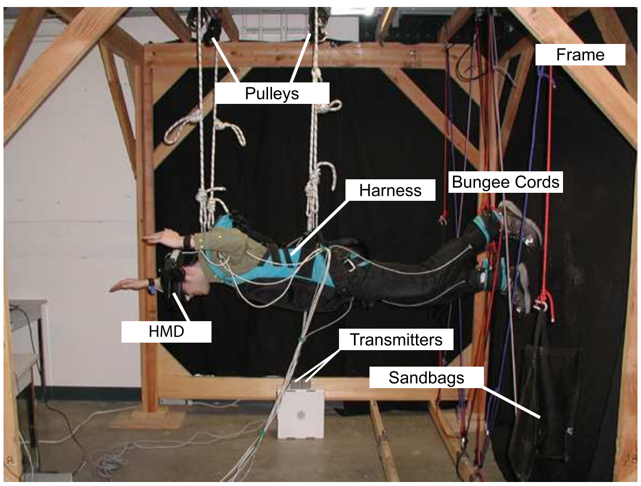

Figure 2: A profile view of the swimming apparatus.

The rope-pulley system (Figure 3) for the legs is designed to conform to several swimming styles including: front crawl, breast stroke, butterfly stroke, and for those who are not swimmers, dog paddle. For each ankle, we run 5mm static cords through two high ball bearing pulleys, mounted on one of the top beams, with another pair of pulleys on the bottom beam. This forms a rectangle where the diagonally opposing pulleys are connected with additional cords for stability. Between the inner pair of the top and bottom pulleys, there is an ankle brace for securing the swimmer's leg in place. Between the outer pair of top-bottom pulleys, the static cords hold a sandbag which counter-weights the swimmer's leg so that only resistance is provided during kicking. Bungee cords connecting the inner pair of pulleys further help restore the kicking energy, adding buoyancy.

Currently, there are no mechanics designed for the arms. Considering that fast swimming depends more on effective streamlining of the swimmer's body in water than on rapid strokes, the arms are left free to allow smooth movements.

We use straps for attaching the Polhemus Fastrack sensors to the participant. Each strap is made of nylon material and velcro. In all, there are six straps designed to be adjustable

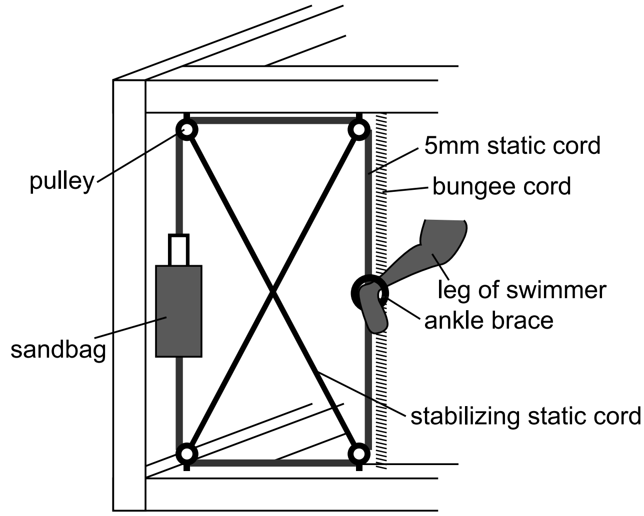

Figure 3: A rear view of the counter-weighted leg support system.

so that they are able to fit everyone while being tight enough to stay on the swimmer while in motion.

2.2.2 The Virtual Ocean Environment

The graphic system (Figure 4 and Figure 5), which is implemented in OpenGL, comprises a sky hemisphere, a sea surface plane, an ocean floor plane, a virtual avatar and various lighting for different times of the day. We wanted different times of the day to alter the sense of reality and timing in the virtual world both for aesthetic and conceptual reasons. The sky hemisphere is texture-mapped with moving clouds. And the ocean floor plane has a rugged plane, texture-mapped with rocks. Both planes are animated to move past the virtual swimmer, making it appear as if the virtual avatar is swimming forward. We also created the sense of time passage through providing sunrise, daytime, sunset and nighttime by moving the sky and effects of lighting. The virtual avatar can be adjusted so that the arms, legs and torso match every participant. This calibration is done using known configurations of the participant as well as measurements combined with the eight measured points from the trackers. For SIGGRAPH'04, though we do not intend to calibrate the system for every participant so that we can maximize the number of people who can try it.

For the sea surface plane waves, we use recurrence relations to solve the partial differential equation for the 2D wave as is standard practice. The height of each grid of the sea surface is calculated with these relations. We approximate the volume of the swimmer with bounding boxes to improve performance and determine when they intersect any of the water grids when they move. When the intersect, they cause the height of the water grids to set to the same as the bounding box. Then waves are made and propagated. If the height is over a pre-defined threshold value and/or the swimming avatar's motion interferes with waves, some particles are made in the air to simulate splashing. The splashing water particles fall down according to a simple gravity model. When the particles reach to the water surface, the grids of surface are set to appropriate height according to the wave model.

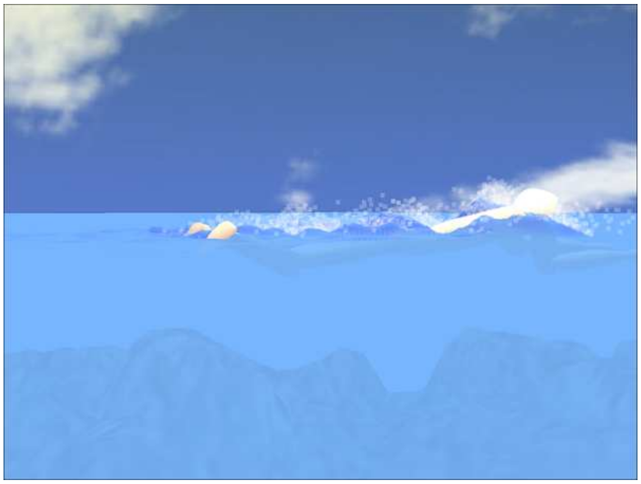

Figure 4: Side view of the SAP environment.

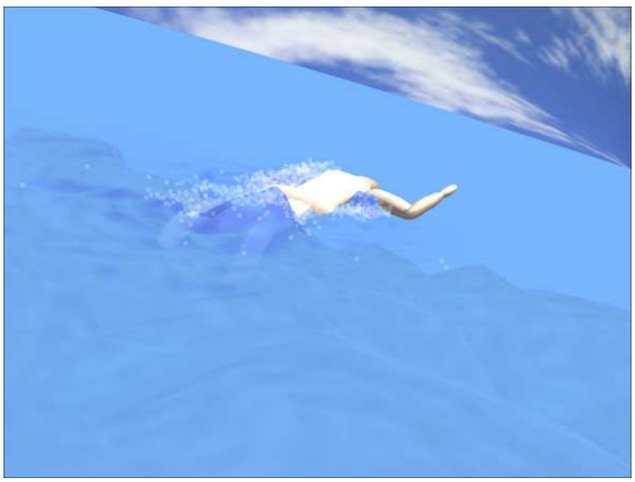

Figure 5: Aerial view of the SAP environment.

2.2.3 Synchronizing the Real World and the Virtual World

A head-mounted display enables the swimmer to see the virtual view, and Polhemus Fastrack sensors approximate the movements of the avatar. We use two Polhemus Fastraks running at different transmitter frequencies; collectively providing eight tracked positions. Figure 6 shows the locations of the 8 Fastrak sensors. In our setup, we have a sensor for:

1. tracking the swimmer's head: the orientation of this sensor determines how we adjust the scene camera to up-date the swimmer's view;

2. tracking the swimmer's wrists and biceps: arm movements are determined using vectors formed by approximated shoulder and elbow positions;

3. tracking the swimmer's ankles: we approximate knee positions and legs positions algorithmically;

4. tracking the swimmer's abdomen: the abdomen and approximated shoulder positions let us approximate the orientation and size of torso.

Since we use eight sensors and the errors due to miscalibration are not so significant, we intend to use only a generic calibration at SIGGRAPH'04. This will allow us to get people into and out-of the system quickly. In our experience within our lab, this has produced good results.

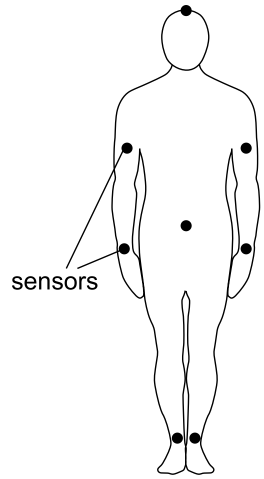

Figure 6: Locations of the sensors on the swimmer.

2.3 Observed User Experiences

Those who have tried out our virtual swimming interface included computer science graduate students, SAP performance artists, researchers, and volunteers. Most feel like they are swimming when suspended in the apparatus. Responses to the mechanics of the apparatus have been positive. People like the resistance and buoyancy of the rope-pulley system that simulates the kicking-in-water feeling.

The graphics currently give a sense of moving along the surface of the water. Our efforts for generating splashes and waves interactively works well. With the addition of other texturing effects we can produce game-like realism. The necessary steps to do this are not technically difficult and are more development than research, thus, it has not been our focus. However, we intend to add them for the Emerging Technologies exhibition to further enhance the aesthetics of the installation. At this moment, we have not integrated our sound module to get interactive sounds. However, since we track each particle, we can easily make sounds that are interactive, immersive and water-like. We intend to use the approach from our previous work with interactive water flow with a multi-touch sensitive pad that provides excellent sound [Chen et al. 2002]. As well, additional cosmetic enhancements for creatures, 3D water effects and landmarks are easily added to enhance the experience.

3 Future Directions

The current state of SAP permits one person to experience the virtual swimming fully immersed in the aquatic environment. We project a bird's eye view of the swimmer in the virtual world for the audience to see. The virtual aquatic world may be further developed to invite audience participation as spectating birds and fish. At this point, we will use two HMDs to facilitate easy exchange of participants.

We will add an optional odometer in the scene to inform the swimmer of his/her progress (speed and current location) when swimming across the virtual Pacific Ocean. As well, with additional optimization and graphics hardware, we will add creatures and objects as additional things for the swimmer to see.

As for long term applications, we see three potential directions for this locomotion interface: sports, education and entertainment. As Wyshynski et al. mention in [Wyshynski and Vincent 1993], one of the virtues of locomotion interfaces is that, regardless of the type of activity (e.g. bicycling, walking, running), they all promotes physical fitness. This is due to the fact that one's whole body becomes involved in the interaction. The ever changeable virtual environment is capable of turning these interfaces into a sport simulator; thus, the swimming interface has potential in water sports simulation.

The swimming locomotion interface also offers a new way to explore knowledge bases. Although our swimming apparatus moves in virtual water, it could be used more generally to move in data spaces that use liquid as a metaphor. Operations such as arm strokes, kicking, paddling and diving gain new meaning when used to navigate various data spaces, such as a financial data, molecular models, 3-D artwork, DNA strands and body cavities. For example, medical students could swim through a framework of blood vessels to investigate human anatomy. Similarly, economists could swim through stock exchange statistics to get a sense of the state of the market. The fact that users use their bodies instead of a mouse as natural navigation devices can dramatically heighten the sense of scale, distance meaning, and even self-awareness. Expending energy at a body scale level may allow a person to understand how objects relate to each other in a body scale frame-of-reference. A swimming locomotion interface, therefore, provides a thought-provoking method of exploration, even though the current design focuses on swimming from Los Angeles to Tokyo.

While stand-alone virtual swimming is fun to use, creative use of such technology in an amusement park setting could be beneficial in providing experiences to people who may want to escape the ordinary. Whether it is swimming with dolphins and whales, or swimming to escape enemy pursuit, virtual swimming has potential to address the human craving for an enjoyable, relaxing, educational, and most importantly, safe way to spend leisure time.

4 Interaction with Attendees

4.1 User Experience

Swimming Across the Pacific is both a single and a group experience. Although only one person is in the swimming apparatus at a time, audience participation is strongly encouraged in the context of performance art. When used within an artwork, HMDs are supplied for all participants in addition to the projection, but given the context of SIGGRAPH Emerging Technology, we propose using only a large front or back projecting screen or a CAVE-like environment to showcase the virtual Pacific Environment, so that more people can share the experience.

Participants do not require any training beforehand. All they need to do is wear an HMD, a hangliding harness and wrist and leg bands. We will provide two students to run the demo and assist people in putting on the equipment and strapping him or her securely in the apparatus. While he or she swims, one of the students will help the next person in line to get ready by putting on the second set of harness and equipment. When the first person is done, students will help him or her out of the swimming apparatus. While the first person removes the equipment, the next person can go inside the apparatus.

Due to the large SIGGRAPH crowd, we will limit each user to three minutes in the apparatus only. This means there will be no time to calibrate the system to suit each individual user. This, however, should not impede the experience of virtual swimming. Users will enjoy kicking, paddling, and generally just splashing around.

4.2 Installation

Given the size of the swimming apparatus (8ft x 8ft x 8ft), we need a minimum of 17ft x 17ft x 15ft space for installation. We will ship the parts as well as bring in the tools for constructing the apparatus. The surrounding area of the swimming device needs to be kept free so as not to encumber the kicking movements of the swimmer during performance. The additional leeway is necessary as well because the sandbags may protrude slightly. Figure 7 depicts a top view of the most desirable setting.

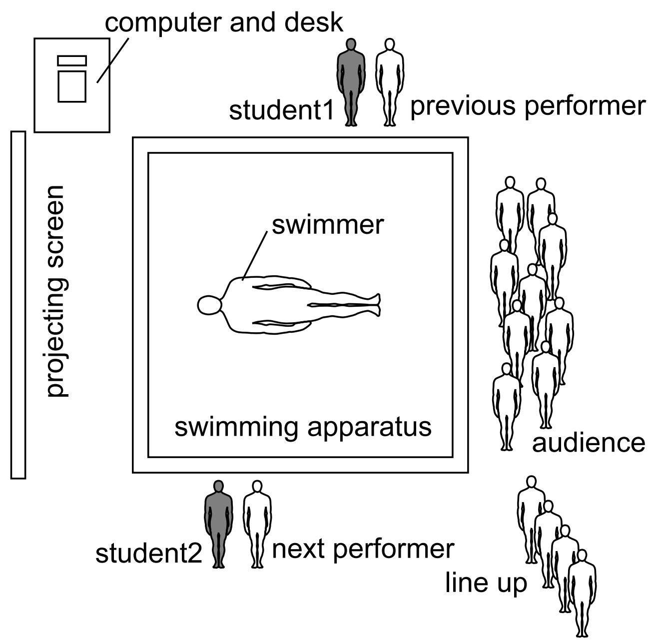

Figure 7: Top view of the swimming apparatus installation.

4.3 Safety

Our system is very robust and safe to use. The swimming cage is configurable, and positions of supporting points (e.g. shoulders, hips, ankles) can be adjusted depending on the size of the person. Its dimensions are enough to allow most taller people to make wide arm strokes without hitting the frame. The system is also capable of supporting heavy swimmers. Each small ball-bearing pulley can support up to 907kg, while each large industrial pulley is capable of supporting up to one ton. These pulleys are used to allow rolling of the torso and vertical kicking of the legs. In keeping with the fact that swimming quickly depends more on effective streamlining of the swimmer's body in the water than it does on rapid stroking [Counsilman 1968], the arms are left free to allow a smooth stroke. Hence, the apparatus supports four swimming styles: front crawl, breast stroke, butterfly and dog paddle (for the aquatically challenged).

To prevent accidental injuries to participating swimmers, we will also provide some floor padding, to prevent people from falling when getting in and out of the swimming apparatus. Floor padding will prevent the problem of a slippery floor, and provide extra cushioning.

Finally, it is very easy to remove the HMD in case a participant experiences seasickness or motion sickness. Likewise, we will have a step ladder so that a participant can easily get out of the harness if necessary. Two students, minimum, will always be at the apparatus to assist.

4.4 Equipment List

The following lists the parts of the swimming apparatus we will bring. We hope the conference can provide us with a table and a chair on which to place our computer and equipment. We would appreciate it if any sponsors who are willing can provide additional head-mounted displays and video cards for our demonstration. The back projecting screen will allow large crowds to observe.

1. 2 hang-gliding harnesses
2. 2 head-mounted displays (any additional ones provided by sponsors can be integrated into the system)
3. 6 velcro straps
4. 1 large front or back projecting screen (10 ft) and projector
5. 1 laptop computer
6. 2 Polhemus Fastraks (4 receivers each)
7. 1 timer
8. 4 large industrial pulleys
9. 8 small high-ball-bearings pulleys
10. 4 bungee cords for leg pulley system
11. 4 carabiners
12. 2 pieces of 1/2 inch thick static cords for harness
13. 8 pieces of 5mm thick static cords for leg pulley system
14. 2 ankle braces
15. 2 sandbags
16. 7 horizontal wood beam for anchoring pulleys
17. 12 wooden beams for the swimming apparatus box frame
18. 8 wooden brackets for reinforcing the swimming apparatus frame

5 Conclusion

Swimming Across the Pacific introduces surface swimming as a unique and novel locomotion interface. It has potential for navigating 3D spaces using a water metaphor and this implies many unrealized applications in education, sport and entertainment. It is comfortable, safe and pleasurable to use, and swimmers require no prior training. It is both an art piece and a scientific innovation. We would very much like to bring the swimming apparatus to SIGGRAPH'04 so that the attendees can experience the dynamic wonder of virtual swimming.

6 Team Members

Swimming Across the Pacific is an on-going project at the Human Communication Technologies Laboratory in the Electrical and Computer Engineering Department of the University of British Columbia. The lead researcher is Dr. Sidney Fels. The SAP implementation team members include Dr. Sidney Fels, Tzu-Pei Grace Chen, Yuichiro Kinoshita, Yasufumi Takama, Kenji Funahashi and Ashley Gadd.

7 Acknowledgements

This project has received funding from : ATR MI&C research laboratories (Japan), NSERC (Canada), UBC (Canada), MAGIC (Canada) and Scream Works Pictures. Our gratitude goes to the many people that have contributed to this project including: Alzek Misheff, Farhan Mohamed, Sachiyo Takahashi, Florian Vogt, and the members of the HCT laboratory at UBC.

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