A VIRTUAL SKIING SYSTEM FOR INTERACTIVE TRAINING AND ENTERTAINMENT

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ABSTRACT

This paper describes a fully interactive virtual reality system in which skier movements are audio-visually reflected in a virtual ski environment. A newly developed ski motion simulator and movement estimation algorithm help create a realistic physical sensation of skiing and allow the system to evaluate skier technique. In the system, a skier stands atop a free-swinging (left-right) foot plate, from which weight shifts are converted into estimated ski movements. A newly developed software architecture, based on distributed processing, gives the flexibility and wide-ranging applicability required for practical implementation; the new architecture allows the system's software to offer an extensive range of functions and to be implemented over an extensive range of audio units, video-projector units, and computer platforms.
Another advantage of this architecture is that it facilitates cooperative work. Multiple virtual skiing systems can easily be connected via a network and operated together to produce a common virtual ski slope. The opportunity for users distant from one another to ski together or to compete at the same time on the same slope adds greatly to the potential pleasures of the systems.
This system is applicable not only to ski training but also to use for general physical exercise and entertainment.

1 Introduction

Sports training systems based on virtual reality technology have been a subject of great interest in the past few years. Virtual reality has great potential to facilitate sports training and also to eliminate much of the boredom of ordinary exercise.

Excellent sports technique can be obtained only through exercise involving actual body motion. Therefore, a virtual reality sports training system should be equipped with a actual body motion simulator. In addition, it would be very pleasurable for the users of such a system to be able to actually move their body and have the body motion appropriately and interactively reflected into the virtual environment in terms of motion pictures, sounds and so on.

Two years ago, we developed a virtual reality system, which successfully proved that virtual reality technology can be applied to ski technique training[Kamijo et al., 1993]. Since the system was designed for fundamental ski technique training from an educational point of view, it allowed skiers to make plow turns only and the creation of entertainment with motion pictures and sound was not given much consideration. It was necessary to develop a system which would have more flexibility in simulating various skiing motions and provide more entertainment value.

In this paper, we report a newly developed virtual skiing system. We have attempted to address the requirement for a ski motion simulator upon which a virtual skier can move freely and in so doing experience a realistic physical sensation of skiing. Generated motion pictures and sound has been improved significantly in terms of virtual reality system entertainment.

Software implementation methodology is another subject involved in developing a virtual skiing system [Nakamura et al., 1994, Lewis et al., 1991, Codella et al., 1992]. The system is required to provide various functions and quality levels mainly concerning motion pictures and sound. However, here is a trade-off between cost and function/quality level. It is desirable for the virtual skiing system software to be flexible and portable to provide various functions and quality levels according to the hardware configuration. We have used network distributed processing technology to develop a software architecture for our virtual reality system which provides the required flexibility and portability. The newly developed virtual skiing system has been designed to provide sufficient functions and quality for ski technique training and entertainment with low-cost hardware using the software architecture.

In our research, we studied several previously developed networked virtual reality systems [Takemura & Kishino 1992, Shinohara et al. 1992]. They facilitate cooperative work among users distant from one another. Virtual skiing system users undoubtedly get a great deal of pleasure by being able to ski together or to compete against each other at the same time on the same slope. The developed software architecture based on network distributed processing technology make it easy to connect multiple virtual skiing system to other units to facilitate cooperative work.

2 Virtual Skiing System Overview

2.1 *System Configuration*

Our virtual skiing system, as described here, consists of a ski motion simulator, an LCD projection unit, a sound unit and two network-connected personal computers(Figure 1).

2.2 *Software Architecture*

To generate a virtual environment, various software processes, such as measuring human actions, calculating physical models and generating motion pictures, are required. Our virtual skiing system has eight processes; skiing movement estimation, ski motion evaluation, ski motion simulator control, system control, slope data management, motion picture generation, sound generation and communication management. These processes communicate with each other as shown in Figure 2.

2.3 *Virtual Skiing*

A skier standing atop the ski motion simulator moves as if he or she were skiing and the movement made are reflected in both picture and sound.

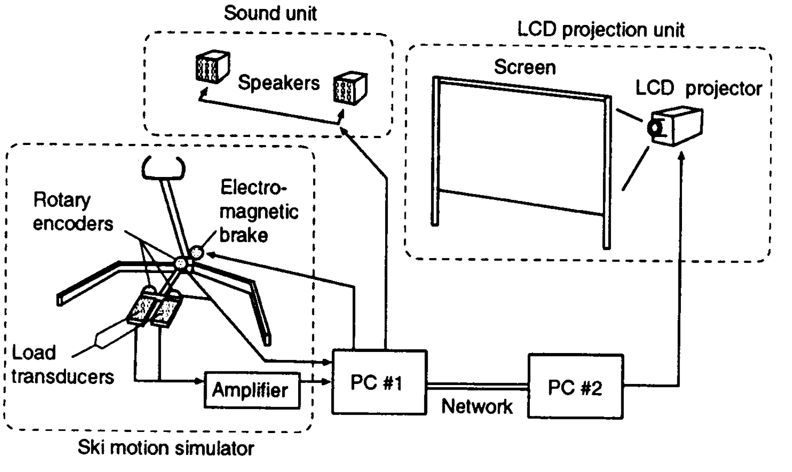

Figure. 1: Virtual skiing system configuration

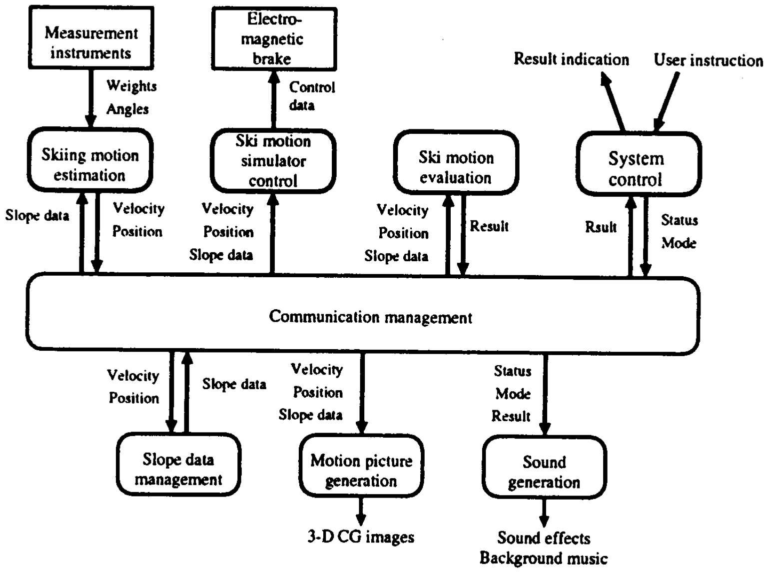

Figure. 2: Software architecture

On the screen, a virtual slope, ski gates and trees are displayed. The skier starts at the top of the slope, skies between the ski gates while dodging obstacles such as trees and goes through the goal gate. The skier time is recorded and the motion data are stored in a PC. The skier can therefore monitor his or her own motion and time. The skiers can not only compare their skiing motions and times but also can compete against each other on the same slope at the same time by connecting several virtual skiing systems through a network. (see Figure 3).

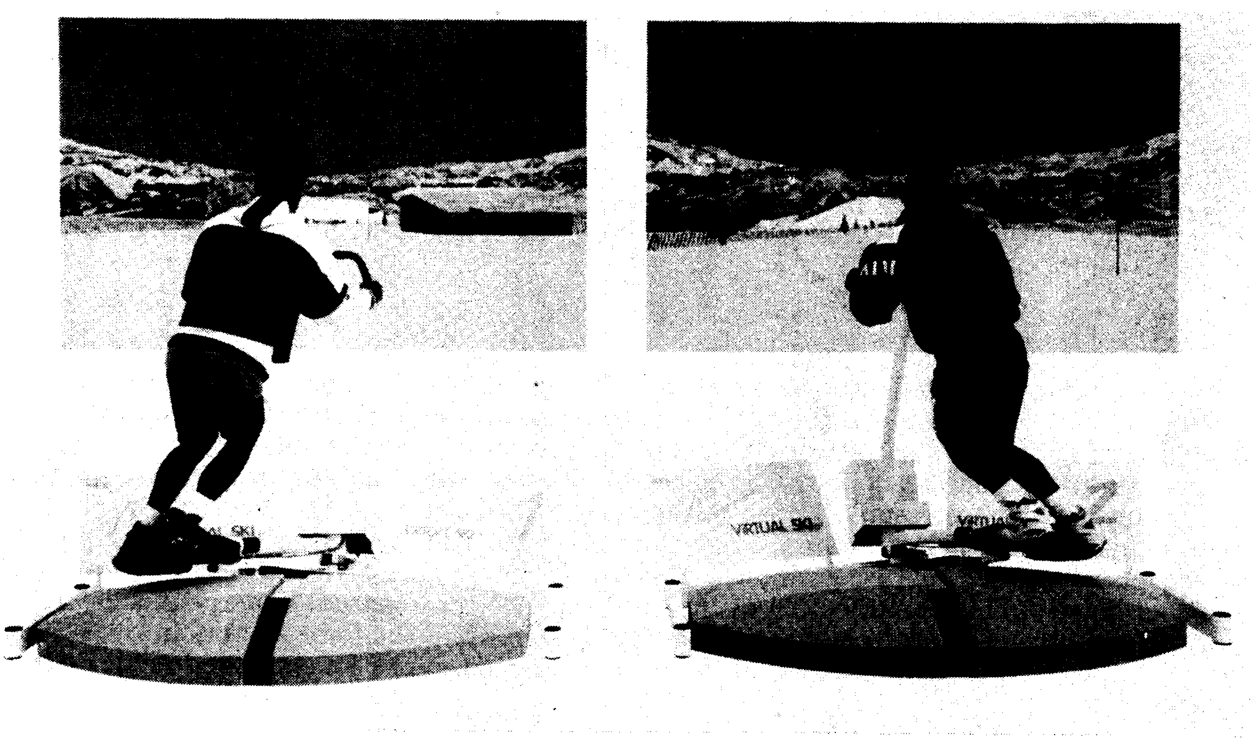

Figure. 3: Virtual skiing

3 Virtual Skiing System

We describe how each process works and related hardware specifications in this section.

3.1 *Skiing Movement Estimation*

The realistic feeling of skiing depends heavily on the quality of the computer graphic images the system displays, and this quality in turn depends on the quality of the simulation which is produced on the basis of the virtual skier's physical movements. We developed a ski motion simulator equipped with several sensors for measuring skiing actions and a skiing-movement estimation algorithm using the measured data.

3.1.1 *Ski Motion Simulator: Measurement Apparatus*

Our newly developed apparatus for measuring a virtual skier's physical movements is an adaptation of a ski-training machine called "PRO SKIFIT". The user sands on the foot plates of the apparatus and, following the image on the screen, pushes and swings on the plates as if gliding and turning on real snow. The modifications for obtaining the physical data of the skier motions are shown in Figure 4.

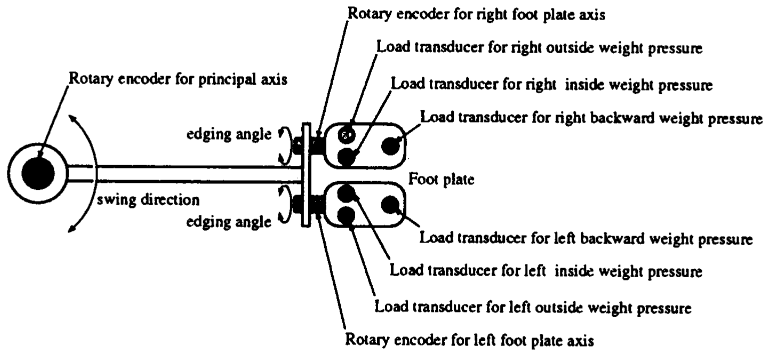

Figure. 4: The arrangement of the load transducers and rotary encoders

Three load transducers are attached under each foot plate for measuring individual foot weight distribution. These transducers are connected via amplifiers to an A/D converter board in one of the PCs. Three rotary encoders are also attached for measuring plate edging angles and swing direction. These rotary encoders are connected to a pulse counter board in the same PC. Then obtained data are processed by following the skiing movement estimation algorithm on the same PC.

3.1.2 *Skiing Movement Estimation*

A skier movement on real snow depends on gravity, on the friction resistance between the bottom surfaces of the skis and the surface of the snow, on the resistance to velocity exerted by oncoming snow against the upturned fronts of the skis, and on air resistance [Tanahashi 1992].

In a turn, the skier bears down on the inside edge to counter the centrifugal force produced by the turning. The pressure exerted is shown as P in Figure 5. The direction of P at any given moment of a turn is determined by the direction and slant angles of skis. Here it is convenient to use a pair of coordinates u and v to help express the force vectors at work. The coordinate v is in the direction of the fall line. The coordinate u is perpendicular to the coordinate v along the surface of the slope. By decomposing the force vectors into the u and v components, virtual skiing movements can be expressed in the following individual motion equations:

[u]

$$M\frac{dv_u}{dt} \approx M\frac{v_{u(t=t_2)} - v_{u(t=t_1)}}{t_2 - t_1} = P\cos\alpha - \mu_k Mg\cos\theta\sin\beta - R_u, \qquad (1)$$

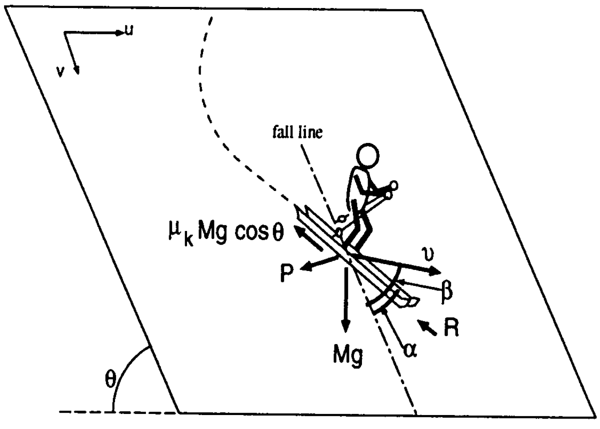

Figure. 5: Forces concerned with turns in actual skiing

[v]

$$M\frac{dv_v}{dt} \approx M\frac{v_{v(t=t_2)} - v_{v(t=t_1)}}{t_2 - t_1} = Mg\sin\theta - \mu_k Mg\cos\theta\cos\beta - P\sin\alpha - R_v, \qquad (2)$$

where M is the mass of the skier including skis, v_u and v_v are velocities in the direction of the u and v coordinates, respectively, g is gravity, P is the pressure shown in Figure 5, θ is the inclination of the virtual slope, α is the direction of the skis, β is the direction of velocity, μ_k is friction resistance, R_u and R_v are the snow resistances, and t is time. t_1 and t_2 are given instants during a ski run.

The values of M, P and α can be measured with the measurement apparatus. The slope data management process determines g, θ, μ_k, R_u and R_v. The motion estimation process keeps track of time(t, t_1, t_2), and it calculates β from v_u and v_v. Once the initial values are given, the accelerations, skiing velocities and position can be calculated at every time step according to the virtual-skier actions.

3.2 *Ski Motion Simulator Control*

The ski motion simulator has two springs which tend to pull the foot plates back toward the neutral position in opposition to swing actions. This mechanism is necessary to realize short swing turns, but it can make it difficult to turn slowly or to move diagonally across the virtual slope. Additionally, the springs absorb quick swing motions, which can cause an unnatural response to a skier's movements in short turns and edging.

We have managed to correct this problem by attaching an electro-magnetic brake to the ski motion simulator at the swing pivot (See Figure 6). The brake controls mechanical resistance in the foot plate swing so as to create a more realistic sensation of skiing than is possible with the original machine. The brake is connected to a D/A converter board in the same PC processing the skiing movement estimation. The ski motion simulator control process determines whether the brake is applied or released using the data measured in the skiing movement estimation process.

When the skier moves the foot plate from one side to the other while keeping his or her weight outside, this action is regarded as a long turn. In this case, the brake is applied to keep the foot plate outside. After that, the skier tries to move the foot plate to the other side again. This reduces the outside weight significantly and the brake is released. When the skier tries to make a short turn, he or she moves from one side to the other immediately, and thus the principal axis direction is small and the weight balance is not maintained. Therefore, the brake is not applied and the skier can move as he or she wants.

In this way, the ski motion simulator control process achieves a variety of long and short turn actions while providing the skier with a realistic feeling of skiing.

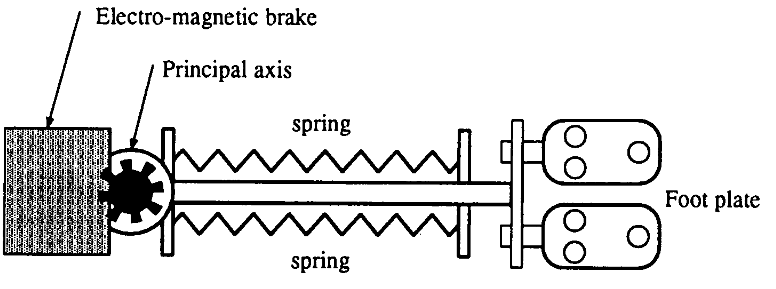

Figure. 6: The arrangement of the springs and an electro-magnetic brake

3.3 *Slope Data Management*

The slope data management process manages shape data, position data and slope data. Shape data consist of three-dimensional polygon data of such objects as slope surface, ski gates, trees and lodges. Position data specify object positions. Slope data express the inclination and surface conditions of the virtual slope.

Since the amount of data involved is very large, all of it cannot be stored in PC memories and high CPU power is required to process it. The slope data is therefore divided into rectangular blocks as shown in Figure 7 and the data is managed block by block. Each block consists of normal directions of the surface for the slope angle, friction coefficients for the snow property and no more than one object (e.g. ski gates, trees). This process obtains the skier current velocity and position data from the skiing movement estimation process and determines the blocks expected to be required by other processes for calculating. Then the process puts the blocks as slope data into other processes.

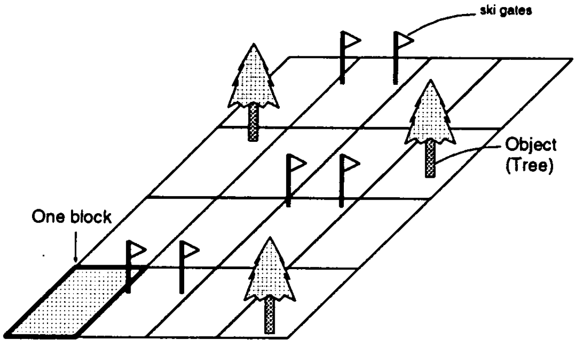

Figure. 7: Divided slope data

3.4 *Motion Evaluation*

The motion evaluation process evaluates a skier's motion using skier velocity and position data obtained from skiing motion estimation process and current slope data obtained from the slope data management process.

The current system manages two kinds of evaluation. One evaluation is checking for collisions between skiers and objects. Since sometime is required for collision to be reflected in motion pictures and sounds, it is necessary to detect collisions in advance. Figure 8 shows how our system forecasts collisions. A line segment for each object is defined in advance. It is assumed a skier will continue to go in the current direction at the current speed for a certain time. When the skier's path crosses the line segment, it is determined that a collision has occurred.

The process checks two types of collisions. One type is when a skier fails to pass through

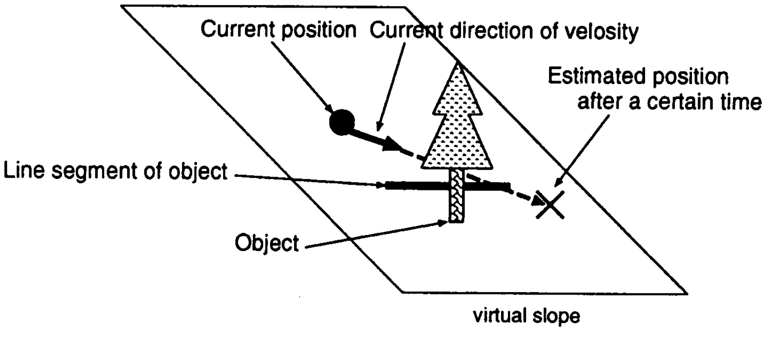

Figure. 8: A collision detection method

a ski gate. In an actual ski competition, failure to pass through a gate means the skier will be disqualified. In our system, to make it more enjoyable for the users, all skiers can continue to do the virtual skiing until they pass through the goal gate but they are assessed a penalty time when they fail to pass through a gate, and their total penalty time for the run is added up. The other type is when a skier hits a obstacle such as a tree, lodge or barrier. When such a collision is detected, the skier virtually falls down. The skier then starts to ski again at the same point five seconds later but at the initial speed and in the initial direction.

The second evaluation is checking ski technique. The ski technique is evaluated simply on the basis of weight shift balance. Generally, the center of a weight shift should be to the front of the feet and the inside of the turn. Otherwise, the ski motion is evaluated as incorrect. Various ski technique evaluations are available based on the weight shift balance.

3.5 *Motion Picture Generation*

The motion picture generation process generates the virtual image that the skier sees. The image is generated on a PC with flat shading and texture mapping using a graphic library called "World Tool Kit" and a 3-D graphic accelerator card called "FIRE board" (see Figure 9). The image consists of the virtual slope, the objects on it, and the background landscape. Since the process is required to display not the total field but only that portion which would be within a skier's field of view at any given time, the quality of moving images is greatly improved over systems which attempt to give a full visual rendering. Even with the small PCs used in our experimental system, we were able to achieve the relatively high rate of nine to ten frames per second.

3.6 *Sound Generation*

Generated sound is classified into three categories, realistic sound, supplementary sound and entertaining sound. Realistic sound means the sound is actually generated by the skiing process, e.g. the sliding sound generated by the skis running over the snow. The volume and tone is controlled according to the force to the slope and the weight shift balance. Supplementary sound is introduced to give additional information to a skier. For example, a chime rings when the skier passes a ski gate in this system. Entertaining sound is background music provided for skiers' enjoyment and to give them the feeling of being at an actual ski competition. From a technical point of view, enabling the skier to ski rhythmically to the background music is an effective training technique.

The sound data format is WAV or MIDI and all the sound data are stored in the main memory of a PC. The process obtains the current system mode and status from the system control process and the evaluation result data from the ski motion evaluation process. The process then generates sounds on the basis of the data.

Several kinds of sound have to be generated sound at the same time as the motion picture is updated. However, the time required to generate a motion picture is different from that required for generating sounds. The process therefore uses trimmed seconds to adjust the timing as required.

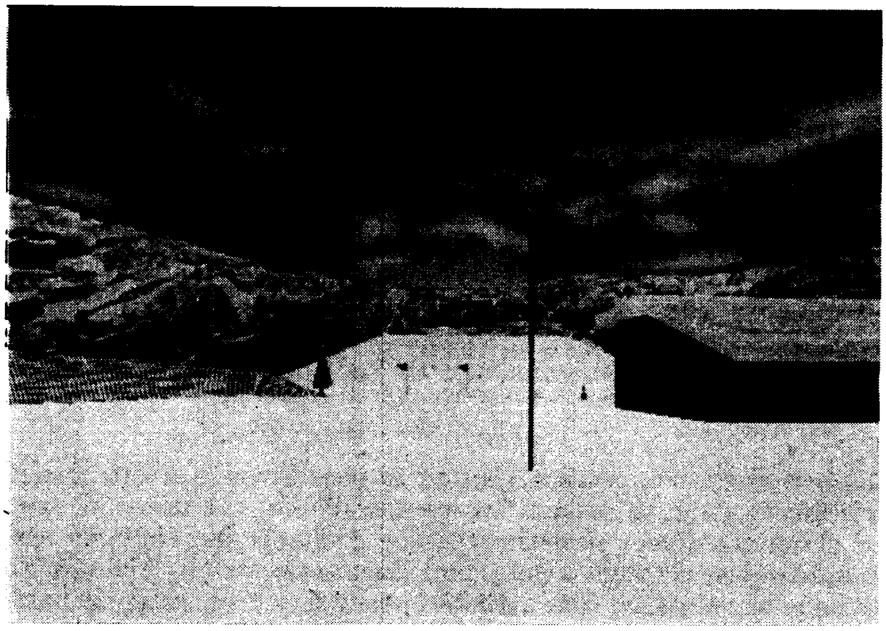

Figure. 9: An image of virtual slope

3.7 *System Control*

The system control process is used for changing among the system's various operation modes and status classification in accordance with skier instructions. The modes indicate which slope course is being used and whether the competition is networked with another system skier. The current system has three courses: one each for novices, experienced skiers, and experts. Status classifications indicate what the system is processing, e.g. "course selection", "weight calibration", "start ready", "ski run" and "score display".

Using a simple user interface pad, skiers can instruct the system to go, stop, reset, pause, etc. They can also fully instruct the system by using the PC keyboard and monitor. In the monitor, various data such as skiing time, passing gates, missing gates, weight shift balance, foot plate angles, principal axis direction, system mode and status are displayed.

3.8 *Communication Management*

The process described above communicate with each other through a communication management process. This process was developed using virtual reality system architecture based on network distributed processing. This architecture allows a virtual reality system to use several low-cost PCs instead of an expensive powerful workstation, to freely connect PCs with required functions, to connect several PCs over a long distance and to run various processes in parallel. Since the architecture also achieves concealed network communication procedures and process independence, developers can implement each process easily.

3.8.1 *Virtual Reality System Architecture*

Figure 10 shows a virtual skiing system example implemented on the developed virtual reality system architecture. Initially, every process declares data size and its identification number(ID) and the communication management process assigns a certain amount of shared data to it. Each process that accesses the data is required to know the ID for it, and it uses the ID to send/write or read requests. Since data size and offset are designated with the request, the process can access a part of the shared data. Several requests are sent as one packet and thus the total amount of communication and time is reduced.

In the case when the communication management process and another process are running on the same machine, the communication procedure is merely to make a memory copy. In

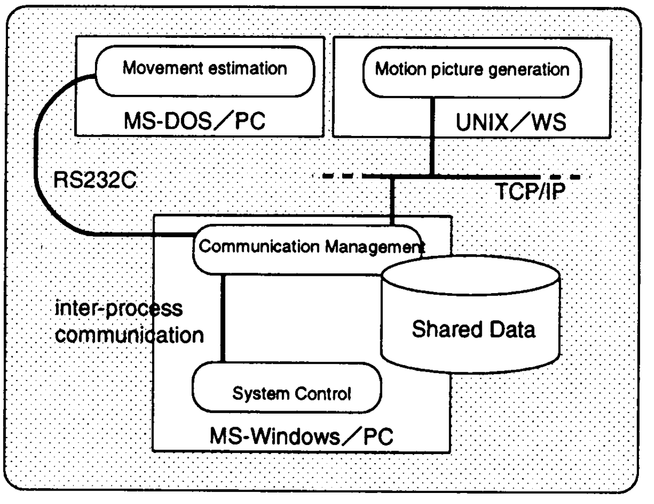

Figure. 10: An example virtual skiing system configuration

In the case when the communication management process and another process are running on the same machine, the communication procedure is merely to make a memory copy. In the event they are running on different PCs, the procedure transfers data via the network using TCP/IP protocol or RS-232C. All communication interfaces are exactly the same for the different manners of communication. The manner is determined by compilation options relevant to the hardware configurations. The process and the interfaces are implemented by C language on UNIX, MS-DOS and MS-Windows. Since they are independent of each others processing programs, they can be easily ported for other network protocol, communication lines and operating systems.

It is useless to re-read data that has not been updated since the process reads it last of all. To avoid such waste, the communication management process memorizes when each process reads the data and does not send data which has not been updated even upon request.

If the process runs and writes the data fluently but only a few of them are read by other processes and most of them are not read, the process might maintain too much processing or communication resources. The process should run at a slow speed and share more processing and communication resources with other processes. For that purpose, the process can ask the communication management process if the data has been read by other processes since the data was updated.

To achieve effective distributed processing, a process which requires a large amount of processing power should run alone or with fewer processes than has been used. However, a process which requires a large amount of communication data or shared data should run on the same computer as that which the communication management process is running on, because the processing power and time for communication required is lessened. Such process arrangement can be determined by compilation options.

Single task operating systems, such as MS-DOS, cannot run several processes in parallel. To allow processes to run on single task operating systems, the processes are implemented as functions, which are called periodically from the main function. Each process, the amount of which is a subject of the implementation, starts in turn and then returns to the main function. To facilitate easy implementation and cooperative work with other processes, it may be suitable for the process read a block from the shared data, process it, and then write it to the shared data in its turn.

3.8.2 *Cooperative Skiing*

Several virtual skiing systems can be connected via network to run together for cooperative skiing. Skiers on the systems ski on a common virtual slope and compete with each other. Since the architecture used for the virtual skiing system is based on network distributed processing technology, only minor modification is required for connection.

Shared data sets for each virtual skiing system are prepared. Each system writes its own data on its shared data block and reads the data on all shared data blocks to run together. For example, the system reads the movement of all skiers and other skiers in front are displayed on the motion picture. The processing is almost the same as that without co-skiers. Such cooperative skiing is a very pleasurable experience which skiers can enjoy even if they are a long distance away from each other.

4 Result

We have successfully developed a virtual reality skiing system which measures the same actions used as in actual skiing, in the process providing users with not only skiing fun but also physical exercise. The system also enables users to learn to ski better by monitoring their motions, such as weight shifting and foot plate edging. It actually composes the several systems which can be connected by network, allowing the skiers to enjoy the pleasure of rendezvous skiing or slalom competition.

Since the virtual skiing system was developed, more than 10,000 people have been able to ski on it. Most of them claimed to enjoy it very much because it is very similar to actual skiing and is a very interactive form of entertainment.

5 Conclusion

The developed virtual reality skiing system offers the users a realistic feeling of skiing and the bodily sensations of actual ski motions. It can be applied to various types of sports training and forms of interactive entertainment. The system architecture achieves a high degree of functionality on the virtual skiing system, establishing a virtual reality system foundation for various types of applications and system configurations.

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