Virtual Simulation Systems and their Applications

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Abstract: The paper describes the historical background of virtual simulation systems. "Virtual" means "having the effect but not the actual form of what is specified". In this respect, all simulations can be regarded as virtual reality. Virtual simulations in this paper, however, refer to those simulations with virtual reality capabilities. Virtual simulation systems are becoming increasingly popular and many applications are based on 3-Dimensional Computer Graphics (3DCG) technologies. The applications cover various areas such as robots, training simulators, game playing, construction business, aerospace field, and medical field. The 3DCG technologies are worthy of attention. The 3D technology renovations are occurring not only in software but also in hardware areas, which accelerates the improvement of virtual reality applications. Robots can be seen as virtual reality of human beings. The paper describes the role of portable phones in robotics. The portable phones are evolving into PDA's (Personal Digital Assistants) and are about to change controls of some robots. Training simulator is a conventional field of virtual simulation application. Examples include driving simulators, flight simulators and flight control simulators. Game playing is a noticeable field of virtual simulation applications. Among many games playing simulators, this paper focuses on those simulators that simulate human opponents. A noticeable example is the famous chess playing machine, Deep Blue, that defeated the World Chess Champion Gary Kasparov, in 1997. The paper defines a measure to evaluate game performances called "game level". The higher the game level is, the more difficult it is to develop a game playing simulator. The discussion will cover Japanese Chess (Shogi), Go Game, etc. The paper also introduces airspace and airport virtual simulation, robot control simulation and acoustic virtual simulation systems for music hall construction.

Keywords: Virtual reality; Simulation; Robotics; Game playing; Acoustic

1. INTRODUCTION

Virtual Simulation System (VSS) is a simulation system based on VR or virtual reality [Rheigold, 1991]. Virtual means, "not existent in the real world', in other words, being "imaginary". From this point of view, "Virtual Reality" is translated into "Kasou Genjitsu" in Japan, which literally means "Imaginary (Hypothetical) Reality". There seems to be a great difference in terms of interpretations between Japanese and English. "Virtual" often means "Substantial". Thus, author's opinion is that " Virtual" means, "having the same effect as the reality".

VR is generally based upon 3-dimensional Computer Graphics (3DCG); however, VR differs from simple 3DCG in that VR enters the actual world, incorporates the coexistent world into itself, and realizes the cooperative or interactive world there. VSS is, thus, broadly applied to the training simulations. According to this basis, our committee is continuing with the survey of state of the art of VSS and VSS applications.

The items so far surveyed are COMTRAC (COMputer-aided TRAffic Control), VSS of CRC (CRC Research Institute, Inc.) and those of SANYO Electric Co., Ltd., TAKENAKA Research & Development Institute and the Earth Simulator of Japan Atomic Energy Research Institute.

The vision is the first among the human senses that VR simulates. But human senses cover not only visual one, but also hearing, tactile, smelling and tasting ones. Therefore, VR should not be mono-sensory, but multi-sensory. At present, however, VR systems are mostly mono-sensory, that is visual VR. One exception is STRADIA (Simulator for Room Acoustic Design and Assessment) of TAKENAKA Research & Development Institute, which will be mentioned later [Hidaka, 1992].

VSS is roughly divided into two large scale one and small scale one. The above-mentioned STRADIA and VSS for Air Traffic Control belong to the former and VSS using HMD (Head Mounted Display) would be examples of the latter.

The medical applications, especially VSS for surgery operations, are the fields that have been left untouched, although we have regarded these as very important. However, It is very fortunate that a paper on this discipline is included in this Proceedings (see the paper by Mukai et al.).

The paper will discuss the following problems:

- The historical background of virtual simulation
- The developments and usages of 3DCG
- Game playing
- Robots and their control
- Training simulators
- Installations, facilities and their operations management
- Concluding remarks

2. THE HISTORICAL BACKGROUND OF VIRTUAL SIMULATION

The term VR is said to have appeared for the first time in 1989, while AI (Artificial Intelligence) was born in early 1950s. It seems that there is much difference between the historical backgrounds of these two terms.

In early 1960s, 3D movies appeared and in 1962, Morton Heilig, the Hollywood-based cinematographer and part-time inventor, patented an arcade-game called Sensorama [Rheigold, 1991]. It was not a computerized game machine, and was no more than a film technology.

Heilig aimed at a game machine playable with a nickel. It was a multi-sensory mechanized marvel that used motion, sound, smells, and even artificial breezes, to convince users they were riding a motorcycle through the street of Brooklyn. Today, Sensorama would be called a VR video game, but in those days, no such thing as video game or VR existed. Multi-sensory experience included tactile-feedback handlebars, 3D stereoscopic view, and wafting aromas such as Jasmine and hibiscus.

Rheingold's comments on Sensorama are very interesting [Rheingold, 1991]. He concluded Sensorama was "a bit like looking up the Wright Brothers and taking their original prototype out for a spin". He also agrees to Heilig's understatement "Sensorama may have been too revolutionary for its time". Although the technical environments were not mature enough for Sensorama in early 1960s, it is true that Sensorama was a herald of VR and we are now in the dream-driven age of Heilig. Further information regarding the history of Sensorama is available at the following URL:

http://retrofuture.com/sensorama.html

Ivan Southerland used the term VR for the first time [Sutherland, 1965 and 1968]. He is considered to be the authority of Computer Graphics (CG). However, the author believes that graphic displays were implemented with computer systems before Ivan Southerland started computer graphics.

The essence of VR is that the depicted world is 3-dimensional, and those who watch the world, coexist with the drawn pictures, and cooperate or interact with the drawn world.

The VR technologies have continued to grow until today and are expected to keep progressing in the future.

3. THE DEVELOPMENTS AND USAGES OF 3DCG

As mentioned before, the essence of VSS is based upon 3DCG. We would like to touch briefly upon the recent trends in 3DCG technologies.

3DCG is not a technology applied for special fields, and its usage has been getting more and more generalized and broadened. 3DCG's growth is very noticeable especially in the video games and related software applications for personal computers.

One of the most remarkable events is the appearance of numerous new graphic chips. For example the following URL has details of the hundreds 3D graphics chips/cards for PC and PC systems with 3D graphics hardware.

http://www.star.t.u-tokyo.ac.jp/~yanagida/pc3d-card.html

According to the editor of the above URL, it is very hard to catch up with new hardware rush.

In order to draw VR pictures, it is indispensable to use special tools. CRC uses the following tools for building their virtual models.

- *MultiGen CreaterTM (MultiGen Inc. USA):* This is the standardized powerful software tool set used for developing real time 3DCG models in visual simulation, interactive games, etc.

- Vega (paradigm Simulation Inc. USA): Vega supports real time 3D display tools realizing various VR effects. Vega provides also sound generation function, which contributes to the real time visual/audio simulation and realization of VR environments. Vega has advanced simulation engine and various tools that afford user-friendly facilities. Vega has highly flexible graphics operating environment LynXTM.

- *VAPS (Virtual Prototypes Inc. USA):* VAPS is a tool to build and evaluate virtual models for various instruments, display screens, etc. in the cockpit. VAPS is also used for household matters.

- *Audio Works (Paradigm Simulation Inc. USA):* Audio Works is a tool to realize 2/3-dimensional sound effects in the real time visual system. The realistic sound in the visual system is very effective.

4. GAME PLAYING

Game playing is a noticeable instance of VSS applications [Nakanishi, 1994a & b; Nakanishi et al., 1995]. Although there area number of game playing simulators, the paper focuses on those simulators that simulate human opponents. The games which appear in our sight at present are firstly "Gomoku-narabe (five-in-a-row)" and "Renju" (a board game similar to Gomoku-narabe with five-in-a-row but with more complicated game rules, or a professional version of Gomoku-narabe with sophisticated rules). Those who want to know more, please refer to the Renju International Federation URL in English version.

http://www.webappcabaret.com/gomoku/en/index.html

Next ones are Othello Game (revised version of *Riversi*), followed by Chess, Shogi (Japanese chess) and Go game. Among these, with regard to Gomoku-narabe, Victor Allis proved that the initial move player always win with 15 X 15 board game in 1992. As for Renju, although several moves that are allowed in Gomoku-narabe are prohibited to lessen advantages of initial move player, the initial move player's advantage still exists. Simulators of high quality have already been developed for Othello, and even world-class players cannot beat them. The LOGSTELLO is the most famous Othello computer, which beat the world champion Ken Murakami in all consecutive 6-game matches in 1997.

The most famous game playing machine is the Deep Blue (DB) that has been developed by IBM as chess machine. DB competed with the world chess champion Gary Kasparov in New York City from May 3rd until May 11th in 1997 and won the 6-game match with win-loss record of 2 to 1 with 3 draws. This was the first occurrence in the history of chess machine.
A great man of letters, Goethe said that the chess is a touchstone to measure human intelligence. The fact that human being has lost the game means he has lost the pride of human being. A human player is said to be able to read 2 or 3 moves ahead in a second, whereas DB reads 200 million moves ahead in a second.

DB is comprised of 32 super computers and 512 parallel processors, and has a big recorded file of opening moves for the past 100 famous chess players in the world. In brief it uses 8 X 8 board, 7 kinds of pieces such as king, queen, rook, bishop, knight, lance and pawn, altogether 16 pieces (32 pieces on both sides). Originally chess was born in ancient India. An offspring went to the East and has grown to chess and another went to the West and has become " Shogi" (Japanese chess). This is the reason why they have some similarities. It should be noted that Shogi has much more complicated rules regarding "promotion" than chess and that with Shogi, unlike Chess, all the prisoners are reusable. The Shogi board is 9 X 9 as opposed to 8 X 8 of chess and the number of pieces used in Shogi is 20 (40 on both sides) versus 16 for chess. These differences make Shogi game by far more complicated when it comes to simulating the game.
A great feature of DB is the numerical evaluation (rating) of game situations. DB can make decision

which move is the most advantageous or disadvantageous instantly according to the rating.

In Shogi and Go-game, computers still have a long way to go. The level of Shogi machine is considered to be amateur 3 or 4 "dan". "dan" and "kyu" represent the strength levels of Shogi or Go players, but there is much difference between amateur and professional. 3 or 4 dan players are fairly strong and probably only several out of a thousand players are found to be of this level. However, they are far below the professional strong players. With regard to Go machine, the level is much lower than that of Shogi machine, and its level is considered to be 5 or 6 "kyu". The players of this level can be found one or two among 10 Go players.

The basic rule of Go-game is very simple. It can be said that it is just a binary game. The difficulty of Go-game comes from its game target. In Shogi and chess the game target is to capture the opponent's king. But in Go game, it has no such a straightforward objective. The final objective of Go game is the broadness of acquired area. The game strategy should be more global than Shogi and chess. Even if one is delighted with the victory of local fight, at the next instant he might be disappointed by the opponent's external influence, which damages his later-on fight. A conventional good rule 1 and 2 cannot be summed up to the better rule 3. We have to keep in mind that the Go game uses 19 X 19 board. So the theater is much broader than other games. The player has to be always careful to the outside condition.

The following numbers compar potential of the three games:

- Chess: 10 to the power of 40
- Shogi: 10 to the power of 80
- Go: 10 to the power of 170

Thus, it .is almost impossible to find the best move through exhaustive or brute-force search in Go game. Under such circumstances, some people say that Go should be played with intuition, which means it is useless to be too deliberate or one should be prompt in action according to one's sixth sense. If so, how can we develop Go machine?
According to the lay view, it takes at least 20 years to complete the Shogi machine that can take rank with Shogi champion. With regard to Go game, it is impossible to develop such a machine within this century, it is said.
Taking into account such circumstances, the author would like to present a few proposals.

4.1 First Proposal

We define "game level (GL)" for various games. The GL is a measure to evaluate the difficulty in developing the game playing simulator.

For instance, GL (Gomoku-narabe)=0, GL(Renju)=1, GL(Othello)=1, GL(chess)=2, GL(Shogi)=5, GL(Go)=10. How to decide the proper GL values to various games is a future problem. In brief, the higher the GL value is, the harder the development of game playing simulator is.

4.2 Second Proposal

Games are usually played on the 2-dimensional board. We introduce 3-dimensional world here, and constitute virtual image through which we can see the potential future game situations.

It is a well-known fact that one can often solve geometric problems more easily through introducing adjoint, or hypothetical (virtual, in a sense) lines.
For conducting international researches on the game playing, the special terminology will become a great barrier. With regard to Shogi,

http://www.mugen-sys.co.jp/Shogi/Terms/index-e.html
http://www.shogi.net/arc/shogi-l/shogi_terms.txt
http://square.umin.ac.jp/bear/clone/shogdict/Shogdict.htm

will assist you.
And with regard to Go,

http://www.cwi.nl/~jansteen/go/
http://nngs.cosmic.org/hmkw/golinks.html
http://www.goban.demon.co.uk/go/main.html

will help you much.
In addition, VR technologies applied to various game machines are noticeable, but we have to give up going into detail here.

5. ROBOTS AND THEIR CONTROL

The robot control is a problem to solve in VR. To control a robot at will is one of the difficult problems. Robots are different from each other. Like human being, each robot has its own personality. Even if the same control algorithm is applied to a robot, it does not always behave the same way. In order to develop an adequate control program including feedback controls and various calibrations based on robot behavior observations, 3DCG is an indispensable tool. IGRIP (Interactive Graphics Robot Instruction Program) is a well-known virtual robot simulator.

Here we would like to touch upon the robot control by mobile (portable) telephone. Recently a big Japanese toy manufacturer announced the development of human robot "DREAM FORCE". It can grasp things by hands, walk on two feet and one can recognize the images seen by the robot through NTT DoCoMo i-mode phone. This robot is 35 cm. tall, weighs 1.4 kg. with built-in micro-motors in its brain, breast, waist, etc. and one can control it by mobile phone. Photos pouring a glass half full of wine and toasting appeared in the recent newspaper. Thus, a new age is approaching when we can watch and control the more human-like PDA (Personal Digital Assistant) through mobile phone terminal and enjoy the symbiosis.

Another popular robot is the pet robot, a brand name of which is "AIBO", a pet dog. Its several features are as follows:

- If you have named it, it will answer to your calling by name.

- It will take photos of a scene it is watching.

- AIBO has its instinct and emotion, and can learn and grow.

- It has its curiosity and has search action.

- It has 6 feelings, thus it gets delighted, sad, surprised, frightened, reluctant, angry, and expresses its feeling by sound, melody, body language or eye lamp.

- It has its instinctive desires and wants to play with others, move its body, eat something or wants to sleep.

- It has the senses of touch, hearing and equilibrium,

- It can respond to various circumstances and environments by its will.

AIBO is really a virtual robot.

6. TRAINING SIMULATORS

The instance where we can expect the largest effect of virtual simulator is the training simulator. The most famous training simulators are the driving simulator and the flight simulator. Sometimes the control systems themselves are used as training simulators. The Virtual Reality Simulation Facility for Traffic Control developed in the Electronic Navigation Research Institute (ENRI) is actually used for evaluating the system performance, but it is also used for training of air traffic controllers. Another example is the COMputer-aided TRAffic Control (COMTRAC) in JR Tokai. COMTRAC actually controls train traffic, but it is also used for training controllers.

The Virtual Reality Simulation Facility of ENRI is comprised of the following facilities.

6.1 Control Tower Simulator

The field of view from the control tower (360 degrees horizontal, 45 degrees vertical.) is simulated along with the sound environment in order to create an atmosphere as close as possible to that of actual controller conducting the activities in the tower. The controller's interface consists of a computerized ATC display and an audio system which enables the controller to give instructions to the pilot. The active aircrafts are controlled by the scenario generator and move according to the directions of air traffic controller.

6.2 Radar Control Simulator

The radar images necessary for simulation of radar control (terminal control and air route control) are generated and displayed.

6.3 Flight Simulator

The field of view from the aircraft cockpit (max. 180 degrees horizontal, max. 60 degrees vertical.) and engine noise are simulated, while the pilot receives and responds to instructions from control tower. The flight simulator's job stick and pedals enable it to simulate both planes and helicopters. The responsiveness of each type of aircraft is realistically computed via aerodynamic simulation software. The flight simulator also contains a Flight Management System (FMS), which enables it to simulate autopilot flight, instrument flight, and futuristic data-link-type air traffic control methods. Flight simulator has curved composite screen, 6 m in diameter, 2.5m in height, 3 channel display system (900 lumens/channel), and has 4 channel audio system. It can simulate A320, B747-400, Bell 412 (helicopter), V-22(VTOL).

6.4 Scenario Generator

According to ENRI [Shiomi et al, 1997], the Scenario Generator processes the simulation scenario in tandem with the Control Tower Simulator and Flight Simulator and controls positions of aircraft and ground vehicles. According to the scenario, various weather effects (wind direction, strength, clouds, visibility) are controlled and the required data is sent to the Radar Control Simulator. Events such as accidents and near-misses can be generated within the scenario. Simultaneous control of over 512 aircrafts and ground vehicles is possible. Maximum refresh rate is 120 Hz. and maximum simulation region is 2,000 km X 2,000 km.

According to ENRI [Shiomi et al., 1997], research activities are being conducted on the Aeronautical Telecommunications Network, Future Global Navigation Satellite System, Enhanced Vision System for Pilots, Aircraft Surveillance Radar, Air Traffic Management, Airborne Collision Avoidance System, and so on.

7. MANAGEMENT AND CONTROL SIMULATORS FOR INSTALLATIONS AND FACILLTIES

Following subsections will describe airport facilities and other installation simulators.

7.1 TAAM Plus

Recently the competition to be the main hub airports in Asia is getting harder and harder. The candidates are the Inchon International Airport in the outskirt of Soule, Shanghai Pudong Airport, Hong Kong International Airport, Kuala Lumpur International Airport, Singapore Changi Airport, Tokyo Narita Airport, Kansai Airport in Osaka and Central Japan International Airport now under construction.

TAAM (Total Airport & Airport Modeller) Plus is the most sophisticated simulation tool of its type available in the aviation industry. It is a simulation model for the decision support, planning, design and analysis. It can simulate traffic at a very detailed level, from the gate of one airport to the gate of another one. The scale of simulation can vary, ranging from local through national to inter-continental. TAAM Plus is the only fast-time gate-to-gate simulator of airspace and airport operations commercially available. It has involved more than 100 person years of effort, accumulating, capturing and systemizing domain knowledge from the international aviation industry. Development has been done in close cooperation with members of the Worldwide TAAM User Group, experts in the aviation domain. Notably, TAAM Plus is the stepping stone for The Preston's (TPG) new wave of simulation and decision support tools.

According to CRC Inc. [TPG & CRC, 2000] , the highlights of TAAM Plus are as follows:

- Fast time and accurate "real world" simulations.
- Local, national, or international scale simulations.
- Can be easily configured for any airport or any airspace anywhere in the world.
- It models the entire airside and airspace environment in detail such as: gates, terminals, pushback, taxiways, terminal airspace, en-route and oceanic air space, in one seamless application.
- Facilitates a general or detailed examination for airspace or airport environments.
- Offers a flexible rule-base, to accommodate different modeling requirements.
- Simulates environments with very high volumes of traffic movement.
- Varies the characteristics of each aircraft randomly, for increased realism.
- Facilitates conflict detection and resolution throughout each simulation.
- Simulates the actions of air traffic controllers in complex airspace environments.
- Can act as a "carrier" or test-bed for a variety of other analytical tools, such as

noise, human factors, cost-benefit, communication models and tools.
- Generates statistical data in a variety of report forms, at different levels of detail.
- Provides direct output to spreadsheet and database tools in-depth analysis.

Other noticeable features are:

- It can make a whole day schedule just in 5 minutes
- It can simulate the process from spot in to spot out continuously
- A special expert system realizes the simulation of controller's directions
- It has 3D multi-color graphic presentation function
- Can be operated by notebook PC

The "Fast Time" vs. "Real Time" is a special expression in TAAM Plus.

- Fast Time requires less resources and cost
- Fast Time provides much faster answers
- Fast Time provides larger visualization and reporting capacity
- Fast Time is less dependent on current data
- Fast Time has significantly more flexibility

The other software provided by TPG [TPG, 2000]:

- TMS: A management tool that enables the scheduling, optimization and planning of airport infrastructure resources in the terminal and apron areas. The unique ' intelligent' rulebase improves productivity and effectiveness for airport planners and operators, through optimizing these limited resources
- SPAR/GS(Ground Staff): A self-contained planning and real-time software application. It provides optimal solutions for allocation, rostering, and tracking of staff resources and daily tasks at labor intensive locations.
- PAXSIM: A graphical passenger movement simulator, allowing real-time or fast-time simulation of passengers as they move about a busy airport terminal. The user has the ability to run the simulation at varying speeds, to zoom in to areas of interest, and to capture all the graphics in an animated AVI file for later analysis.

7.2 STRADIA

A concert hall is capable of producing solemn, warm tones or clear, distinct reverberations and is itself often likened to musical instrument.

During the design stage of a concert hall, however, it is very difficult to predict the kind of sounds that will result from the shape of the hall and the materials used in its construction. Takenaka Corporation [Hidaka,1992] has been wrestling with this problem and recently it developed the world's first simulator for room acoustic design and assessment (STRADIA). STRADIA enables us to experience an accurate simulation of the sound within a hall yet to be constructed by using data related to room size, shape, and the materials used in its construction. This is the realization of a long standing dream of concert hall owners and architects

7.2.1 Components of STRADIA

STRAIDA has the following components:

- *An Analysis of Sound Propagation in a Hall.* Sound reaches the audience as innumerable reflected sounds. The reverberation pattern determines the acoustic characteristics of a room and can be analyzed by means of a computer-aided acoustic design system (AUDIA: Auditorium Design Instrument for Acoustics).

- *The Digital Synthesizing Simulator.* The direction, delay and attenuation data created by AUDIA system is sent to simulator. When music is played from digital cassette, the digital processor uses this data to send sound to the appropriate speaker with correct delay and attenuation, thereby simulating the characteristics of specific hall.

- *A Music Source Recording from an Anechoic Room.* When synthesizing sound characteristics, a recording, which contains reflected sound, is of no use. Therefore, in order to pick up only the sound that comes directly from the sound source, a digital recording was made in an anechoic room.

8. CONCLUDING REMARKS

This paper has reviewed the state of the art and future of virtual simulation systems. Their applications cover a number of disciplines including: medical/home care, surgical operation rehabilitation, network multi-media communication, entertainment/amusement, commodity planning, design presentation are regarded as particularly promising in the future. The technical problems to solve are image input, 3D mouse, space ball, 3D digitizer, acoustic display, tangibility and power sensibility displays, and so on.

As for the VR surgical operation, please refer to the following report.

Report: The Cutting Edge of Virtual Reality, *Medical Technology;* From The Economist print edition, March 22nd,2001.

http://www.economist.com/diplayStory.cfm ?Story_ID=539772

9. ACHNOLEDGEMENTS

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