VIRTUAL LOCOMOTION CONCEPTS AND METRICS STUDY

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ABSTRACT

The U.S. Army Simulation and Training Technology Center (STTC) has been performing research and development in the field of virtual locomotion. This technical challenge has been thoroughly researched for many years and many locomotion concept systems have been designed, developed and studied over the years but yet still a viable system is lacking. The basis of these studies is that while immersed into a virtual training environment, a soldier must be able to move a virtual representation (i.e. avatar) of himself in the virtual environment as he moves in the real world. The movements of the virtual character should also provide realistic and human-like motions in order to maintain the soldier's feeling of immersiveness so that he remains focused on completing his mission. As there have been many forms of virtual locomotion, the STTC decided that it would be beneficial to perform a Trade Study of virtual locomotion systems from various companies and agencies. The first goal of this work was to investigate different forms of virtual locomotion systems to determine if there are any links or similarities in developed systems. Another goal was to determine if there were any components that are essential to the design and development of a virtual locomotion system. The last goal was to investigate the systems to identify what system(s) provided the most human-like immersive experience. A number of requirements and metrics were determined along with evaluation scenarios and criteria to quantify them. This paper discusses the results of the study of the virtual locomotion systems, how the systems work and the techniques that allow a user to use the various systems. This paper will discuss various forms of locomotion devices and systems and will present the results, lessons learned and other insights learned during this study.

KEYWORDS

Dismounted Soldier, Locomotion, Mission Rehearsal, Virtual Environment, Immersion

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INTRODUCTION

Locomotion is defined as "the act or power of moving from place to place". Natural human locomotion is the self-propelled movement of a person through the real world, typically performed on foot (Templeman, Denbrook & Sibert 1999). When associated with a Virtual Environment (VE), such as those for military training and commercial retail video games, the term is referred to as 'virtual locomotion'. Virtual locomotion is described as a control technique for allowing a person to move in a natural way over long distances in the VE, while remaining within a relatively small physical space (Templeman, Denbrook & Sibert 1999). Virtual locomotion should also closely mimic natural human locomotion as realistically as possible. This idea has been the main goal of researchers for many, many years, yet still a viable virtual locomotion system has still not been developed.

The U.S. Army Simulation and Training Technology Center (STTC) has been researching and developing virtual locomotion concepts and prototypes in order to find a realistic and human-like system. In this paper, multiple locomotion concepts and systems will be discussed that have been developed by multiple companies and agencies to determine three main research goals. The first goal was to investigate different forms of virtual locomotion systems to determine if there are any links or similarities in developed systems. The second goal was to determine if there were any components that are essential to the design and development of a virtual locomotion system. Having found the essential pieces that produce virtual locomotion, the researchers could then use the previous research to answer our third goal. The third goal was to investigate the systems to identify what system(s) provided the most human-like immersive experience. Virtual locomotion performed in a VE should closely mimic natural human locomotion to the best of its abilities. As no virtual locomotion system can exactly match natural human locomotion, we will discuss those systems that closely mimic or that are approaching the goal of becoming more human-like in nature. Quantifiable metrics were developed to try to help categorize each locomotion system and to separate certain locomotion concepts from others for the sake of comparison. Categorizing the concepts and systems was not an easy task and some of the locomotion concepts fit into multiple categories. This will be discussed later in the paper. This paper also discusses the results, lessons learned and other insights learned while performing this research study.

BACKGROUND

The study of locomotion dates back for many, many years and has been a subject of researchers in multiple fields. The origins of the study of locomotion go back to researchers studying archeological finds and studying the way dinosaurs, birds and other species were able to move from one place to another and to study the different ways that the animals performed these movements. In the 1970's the term "artificial reality", was coined by Myron Krueger, but the term "virtual reality" can be traced back to Antonin Artuad; a French playwright, actor, poet and director (Davis, E. 1998). The development of virtual reality allowed a user to look around and view multiple VEs, but users soon wanted a capability that could be used to explore the virtual environments in full and up close. Soon a need for virtual locomotion became necessary. During this same time many roboticists from all over the world were also becoming increasingly interested in locomotion for bipedal robots. Virtual locomotion was also introduced in the 1980's to a vast majority of users with the introduction of the video game. Virtual locomotion had now invaded many households through the invention of video games.

In a video game, the user is immersed into a virtual world and then presented with some sort of challenge. These challenges include driving a simulated car while racing other computer generated cars or by moving through the VE collecting items to use to gain access to the next level or to find a weapon needed to destroy the "boss" in order to continue to the next level. During the past ten years, video games and computer gaming have become more realistic and have seen a huge increase in usage due to the overall increase of the power and size of graphics cards, processor speed and memory found in today's computers. Video game systems have also seen a huge rise over the years in usage due to the crisp, sharp images of models, terrain and objects. The amount of control a user has to interact with the game has also dramatically increased over the last ten years. Advances in joysticks, feedback, and the ability to play games with anyone, anywhere have all made the typical video gaming system less than typical. The ability to play a game sitting at your own home with someone else anywhere in the world is of huge interest for many users and has helped propel the game system industry into the future. All current gaming systems allow all users to play by themselves, with friends or with complete strangers via on-line play. As with distributed computer game platforms, the commercial video game systems also allow a user to play other gamers all over the world, from across the street to across the globe.

With the continued increase in interest and in money, commercial games have multiplied not only in title, but also in production. The United States military has also found a key interest in using these already popular games to help train their soldiers for a variety of different scenarios against different opponents. The military has looked at the commercial video game industry to help make games that appeal to soldiers and soon-to- be soldiers using games as recruitment tools in some cases and for training in other cases. The military has some different needs from games that generally differ from commercial video games in many different aspects. Video games typically use levels that users have to move through to get to an end goal or the next level whereas the military is not focused on levels or finding key items or destroying bosses to advance to the next level. Military training scenarios need larger terrains that closely mimic if not exactly replicate real live terrain where combat battles may be fought or for training of soldiers in a variety of different settings and conditions that would normally have the soldier travelling. Video games also typically require you to shoot many items and people whereas military training does not always involve shooting everything in sight. Because of these clear distinctions and others, the military has been increasingly looking to VEs to effectively train their soldiers. Advances in the fields of real-time computer graphics, behavioral animation and artificial intelligence are enhancing our ability to create realistic VEs in which participants can acquire skills that are normally too costly, dangerous or otherwise impossible to achieve using traditional training methods (Lane, Marshall and Roberts 2006). As the cost of war continues to increase, many leaders are turning toward VEs to help train their soldiers to be ready and able to deal with any scenario in any condition. Virtual locomotion is necessary for dismounted soldiers to train in virtual environment training scenarios in order to continue the soldier's sense of realism and immersion. The soldier must perform virtual locomotion that closely matches that of natural human locomotion or he will lose the sense of immersion in the VE. A virtual locomotion control man-machine interface would not only increase the immersiveness and fidelity of virtual training simulations but would also help maximize training effectiveness by reducing the time required to achieve the same level of proficiency in a live situation (Lane, Marshall and Roberts 2006).

LOCOMOTION

Natural human locomotion is based on a few scientific principles. Locomotion control is divided into two components: control over the direction of motion (steering) and control over the rate of motion (speed) (Templeman, Denbrook & Sibert 1999). Both actions should work together to produce locomotion. The speed of locomotion can be controlled by gait frequency and/or foot forces either through touching the floor or through moving the locomotion device that is used to produce motion and speed. Steering control is broken into two separate parts: direction and style. The direction of locomotion is controlled through either waist steering, head steering or feet steering with waist steering being the most commonly used directional steering. The style of locomotion is controlled by assuming a body posture normally associated with a particular movement (e.g. running, stepping, etc…).

In describing locomotion, one must define coordinate systems as locomotion deals with translational and rotational movement. For translational movement, typically the Cartesian coordinate system is used to provide the X, Y and Z translational directional movement. This is referred to as a 3 Degrees of Freedom (DOF) coordinate system.

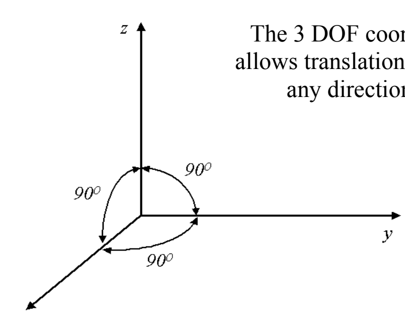

Figure 1. Cartesian Coordinate System of 3 Degrees of Freedom

When studying locomotion systems, to understand the full position and pose orientation of the avatar, rotational movement must also be accounted for. For rotational movement a six Degree of Freedom (6 DOF) system must be used which includes the translational movement in three directions of the axes (X, Y and Z) as well as the rotation movement around each axes (Roll, Pitch and Yaw).

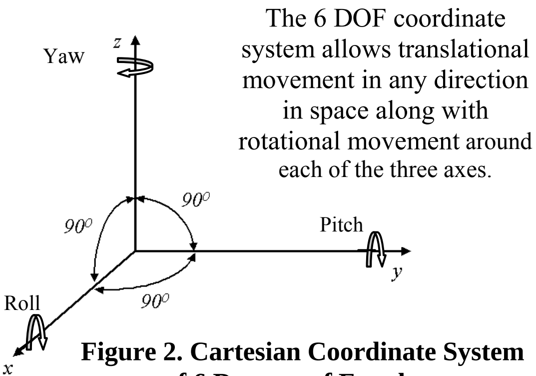

Figure 2. Cartesian Coordinate System of 6 Degrees of Freedom

LOCOMOTION TRADE STUDY

The STTC has been performing work in the area of virtual locomotion for some years now researching different virtual locomotion systems to use for dismounted soldier virtual locomotion. Recently, a trade study was performed to study and research past and current systems that have been designed and developed to allow an avatar to perform virtual locomotion. The researchers wanted to define the true key pieces that are necessary in developing a realistic and natural virtual locomotion system; including all the different motion gestures a real human requires to perform natural human locomotion. In addition to that, the researchers wanted to define, categorize, apply metrics and summarize the multiple virtual locomotion concepts that had been researched. The trade study covers multiple concepts for virtual locomotion systems, but does not choose a "perfect" system as different applications require different solutions. Each system was defined, researched, categorized by type of locomotion concept and summarized based off of the information that was gathered for each system. At the end of the study, the gathered information was used to form a hypothesis on what locomotion system(s) provided the most human-like and realistic concept.

METRICS

Before metrics can be postulated, a set of requirements must be presented as a guideline for their derivation. This section is organized as such. Many of the references discuss over-all requirements for "simulating a natural capability".

The metrics that were focused on were the metrics that would help meet the research goals. The team wanted to: (a) find as many locomotion systems as possible to research, (b) find any similarities between the systems and (c) find the system(s) that produced the most human-like realistic virtual locomotion.

Accuracy

To determine the accuracy of each system compared to other systems, we gathered specification sheets from various vendors and attempted to verify their specifications through asking them to show us their testing and experiments where they accomplished the specifications that they claimed. The only true way to decipher the true accuracy of any of the systems versus another system would be to actually take the system and perform an independent test to quantify the actual specifications that are stated by each company. The accuracy of claims for each system could then be identified in order to compare and contrast to other systems in the same category as some systems just do not have comparable metrics because of the design of the various systems.

Latency

Latency is determined based on two factors, the frame-rate to the immersed user (client) and the update rate of the computer generated aspects of the VE and the virtual locomotion system. Time to load terrain, or if terrain is built in succession, how long to move from one terrain generated scenario to the next, etc. Also the time that the human gives the command to walk, the time it takes for the computer to recognize the "walk" instruction and allows that instruction to occur would also add to the latency of the system. Similarly to accuracy, latency can only be verified by testing the locomotion system as an independent researcher to verify the actual frame rates, latency in computer cycles, etc. It is also important to note that all systems studied would have to use the same Image Generator from the same VE to make a fair comparison to other systems.

Human Factors

Human Factors questionnaires would also be used to collect information from various users who test the system. Motion sickness, ease-of-use, comfort rating, constraints, movement around obstacles, ease of performing locomotion, etc…are all human factors questions that could be asked in questionnaires to produce some qualifiable data from the different virtual locomotion systems. The researchers must be careful to divide certain criteria that could come from other sources besides the locomotion concept, such as motion sickness could result from the soldier's activities the night before, the movement of the scenery in the VE moving too fast or it could simply come from not adjusting the Head Mounted Device (HMD) correctly that is used and not the locomotion system itself.

Fatigue

Any virtual locomotion system that can be categorized as being human-like must produce some sort of fatigue on the user. Surely the amount of fatigue will not exactly match the natural human fatigue levels because of the typical confined space that virtual locomotion systems come with, but some level must be created. Locomotion devices that use joysticks create less fatigue than those that use running in place and motion platforms. The other main issue with fatigue is how to properly measure fatigue? This has been an on-going debate between researchers and no one set of methods has been proven successful.

Speed Control

Speed control is a definable quantifiable metric that can be used to compare each system to another. Experiments of how well speed control is handled are a definite metric that must be tested and compared to each and every virtual locomotion system. Also, how well the virtual locomotion system can be controlled at different speeds is also a quantifiable metric that must be investigated. Ideally, the virtual locomotion controller should be able to sustain the same speed as a human being performing the same movement should be achievable, but with accuracy and latency involved, that achievement is not straightforward.

Steering Control

Steering control is also a quantifiable metric that can be tested and compared between systems. Although many systems use various different methods of steering, they are all still trying to reach the same goal. How steering is performed in each system is also something to watch closely as most virtual locomotion systems that we researched used a wide variety of styles to perform steering control. Again, the goal of steering control is to closely mimic a human's style of steering, but in the virtual systems, latency, accuracy and physics may not allow that to happen exactly.

MOTION GESTURES

Motion gestures are all of the different poses and movements a human must perform to achieve locomotion. Any virtual locomotion must also account for the many types of motion postures and movements required to successfully navigate through and around solids and obstacles placed in the virtual environment. A realistic, human-like virtual locomotion system should contain a capability to allow for each of the following types of poses and movements:

Scanning/Steering - To peer out at or observe repeatedly or sweepingly to a large advance; survey.

Walking – Short upright strides which only have a minor impact on fatigue.

Jogging – Longer upright strides which have a slightly increased impact on fatigue but at a higher speed.

Running – Longer upright strides which have a higher impact on fatigue and a higher speed.

Sprinting – Longest upright strides which have highest impact on fatigue, but can only be maintained for a short period, but the highest speed.

Turning – Generally associated with the pelvis orientation but can also align with the leg and torso (in crouched or prone gesture).

Jumping – Elevating the body through vertical leg force and in some cases transversing horizontally.

Climbing – Use of extremities to grasp and navigate ladders and other vertical items at a slower speed and moderate fatigue,

Crouching – Lowering the torso and legs to allow navigation under obstacles but at a slower speed and moderate fatigue,

Crawling – Lower the entire body (a ka prone) to navigate under very low obstacles, provide cover, and at a slow speed of motion and moderate fatigue.

Swimming - Propelled motion through a liquid medium (*note: swimming was not included in this study as the researchers were interested in human locomotion performed on land.*)

The following figure illustrates these motion gestures.

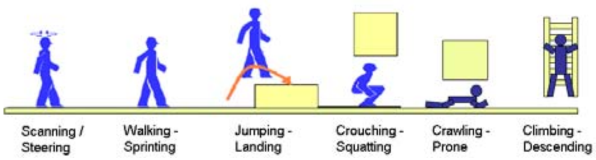

Figure 3. Motion Gestures and Modes

The combinations of motion gestures along with over-riding navigation methods (speed, steering, and scanning) represent multiple combinations by which to test any concept against specific use cases. For each of these combinations, a set of requirements and metrics must be evaluated in order to assess the validity of any specific approach.

In the next section, the initial requirements along with the general metrics are presented which can be used to assess concepts. The author's note, that these requirements (and their use-case need values) have not been formally vetted against Army applications. The process of developing the Locomotion system specifications was out of the scope of this initial trade study.

Straight Motion

Straight motion consists simply of navigating straight line paths in all key directions; forward and backward while keeping your head facing forward. The evaluation scenario should include a sufficient distance to verify all the motion gestures and "speeds" and include any transition of directions.

Curved Motion

Curved motion consists of navigating non-linear (curved) paths similarly in all key directions; forward, backward, and side-to side. The evaluation scenario should include a sufficient distance to verify all the motion gestures and "speeds" and include any transition of directions.

Steering / Scanning Motion

Steering and scanning motion combines the influences of straight and curved motion (with gestures and transitions) but allows for decoupling of view port and motion direction. Further, this combination provides options for the steering reference motion to specific body parts (head, pelvis, thigh, torso, etc). While many "game" systems link the head angle to the steering angle, a true virtual locomotion system must account for these abilities available to live humans.

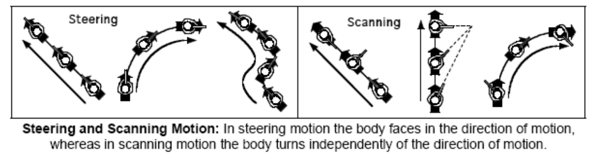

Figure 4. Steering and Scanning Motion (Templeman, J. N., 2003)

TEST COURSE

The virtual environment test course is a relatively simple course with key stressor points such as external stimulus, open versus tight spaces, and all aspects of motion and gesture requirements discussed; including vertical, translational and rotational speed diversity. Most (if not all) of the evaluation points and motion gestures can be combined into this type course.

Like any evaluation scenario, this test requires a common database between virtual environments to quantify metrics; in absolute performance. Since in this study, relative performance is desired, then a common virtual database is required and any differences between image generators, where the live/virtual translation results are measured - must be accounted for.

The test course should include vertical diversity to accommodate the motion gestures related to climbing, crawling, crouching, and walking up and down stairways and all of the other motion gestures that must be used for virtual locomotion.

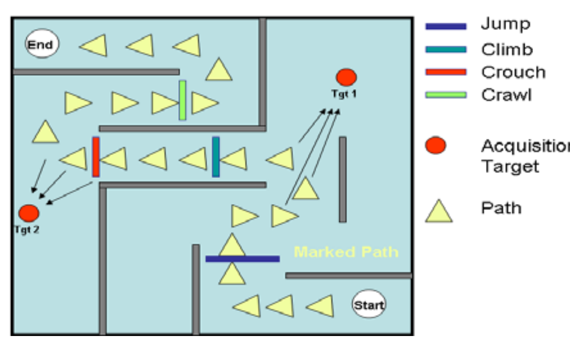

Figure 5. Simple Test Course with Motion Gestures and Obstacle Types

CATEGORIZATION AND CONCEPTS

While reviewing the published information on virtual locomotion concepts a need for categorization emerged; there were so many different locomotion systems and concepts and many with only small variations from others. In the study, an initial set of categories were proposed but by no means were meant to fully encapsulate the novelty of any particular approach. In this section, the major categories are introduced and a concept is used to illustrate each category. The concept described is only for illustration of category and does not constitute any performance assessment or preference by the authors.

Desktop

The desktop category had to be included as the basic interface for humans to navigate and pose in virtual environments. This is the standard interface for gamers and can include a combination of common human interface devices (Mouse, Keyboard, Joystick, Gamepad) for moving and interacting with the virtual environment. Many newer gaming systems are now developing unique controllers and techniques such as allowing the user to use his/her body to also provide movement and control of their avatars. Desktop controllers can use mice and keyboards to perform locomotion. Most commercial gaming systems include either a single pole joystick with buttons or a double pole joystick with multiple buttons. The double pole allows one pole for translation and one for rotation of the avatar. Some of the newer techniques, like the Wii™ Remote Controller, allow users to play games by using their own body movements along with using a variety of hand controllers.

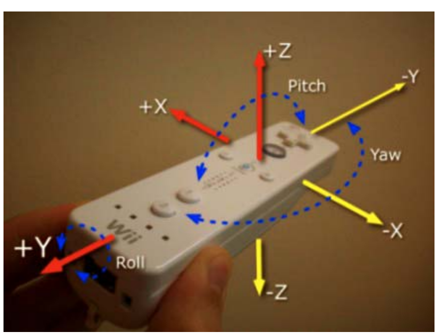

Figure 6. Wii™ Remote Controllers with Axes

This fundamentally unique controller has been used for multiple applications including some that also allow a user to effectively use the remote to perform virtual locomotion (Williamson, Wingrave and LaViola, 2010). Microsoft's X-BOX 360 has also announced a similar motion based system using no controller at all called "Kinect"™ that will allow users to play video games solely with the use of their own body motion. In addition to that, SONY has also announced a new system debuting soon called PlayStation Move™ that will not only allow players to use their bodies as controllers but also to become a part of the video game through Augmented Reality.

The main limitations with desktop systems are that typically you would be sitting down to play the game and your feet would not be moving or helping you to perform locomotion in any way. Some of the newer movement controlled games are trying to overcome this phenomenon, but most of the movement based games are still infantile and lack the accuracy needed for military training applications. Joysticks and buttons are still used in most First Person Shooter (FPS) action games to perform all of the actions of the avatar which is unrealistic in matching human locomotion. The joysticks and buttons also provide the users with tools and methods that you would not have access to in an actual combat environment. Gravity guns, flaming arrows and long distance lasers etc… are put in to games for fun, but do not exist in the real world. Commercial gaming companies may also increase the range of the weapon or the kill radius which may be different for actual combat weapons. Most games include "negative training aspects" such as having access to weapons that do not exist in the real world, joysticks and buttons that allow you to perform actions do not exist in the real world or increased physics allowing you to run faster, jump higher or longer, etc… These actions are quite different between desktop training games and actual combat weaponry.

Hybrid Capture / Controller Systems

A hybrid capture / controller system is one that uses a variety of different methods to allow a user to perform virtual locomotion. Many of these hybrid systems use partial sensors, partial meaning on one leg, thigh, or foot, with a combination of joysticks and buttons to perform locomotion. These systems do not create a large amount of fatigue as most users use joysticks with a desktop system, but usually wear dismounted soldier man-wearable suits so they can stand up as they would in natural human locomotion. The limitations on human locomotion with hybrid systems are that many still use joysticks and buttons to perform translational locomotion without using their feet or hands as they would in the real world. This type of navigation/locomotion control interface can also encumber the maneuverability of soldiers during critical combat tasks such as looking around corners, moving through buildings and stacking on walls (Lane, Marshall and Roberts 2006). Because a soldier's decision-making focus is taken off of the scenario to artificially engage a simulation button, there are tasks introduced that are not present in actual combat (Marshall, H., Garrity, P. et. al.). The buttons and joysticks bring in negative training aspects as they are new devices added to a weapon for training that are not on the soldier's weapon during battle.

The other issue with Hybrid Capture / Controller Systems is that most trainees have a limited amount of space available for them to train in (Sibert, L.E., Templeman, J.N. & Page, R.P. 2004). A person must be able to move naturally through the VE while, in fact, remaining within the bounded physical space of the tracking system. Therefore many of the locomotion systems are tied to the fact that the trainee has to stay within the tracking area of the system while performing virtual locomotion. This usually requires the trainee to run in place or walk in place and while is not truly human-like, it is the closet in approaching being human-like as it does not require a separate device to perform locomotion in. Due to the fact that there is limited area to perform locomotion in, a trainee may have to perform a "proxied" style of interaction to perform in the real world which is then translated into realistic locomotion while in the VE.

Treadmills

Omni-Directional Treadmills (ODTs) are a locomotion concept that has many different systems with various discrepancies between each. In general, an ODT is a device that allows a person to perform locomotion in any direction while the user is standing on a set of treadmills. The ability to move in any direction is how these concepts differ from other systems. These systems have been implemented in various forms for over the last ten years but none have been found to be the virtual locomotion solution. Many systems involve large balls that a human enters and uses his inertia and movement to start the ball, but then changing direction can be somewhat difficult and has caused many first time users to roll over with the ball.

Various forms of treadmill systems have been developed over time including unidirectional treadmills also. With movement only allowed in one direction though, these systems make it hard to steer especially if the user is wearing a HMD to view the virtual environment. Escalating treadmills have also been researched and developed into virtual locomotion systems that use stair-walking and ski-walking exercise systems as there base. Tread mill applications for locomotion have had multiple designs and concepts. Most treadmill systems have problems with inertia and are hard to start and stop at times and very hard to change directions once the treadmill has started. Many users find them hard to use (especially with a HMD on) because it is hard to change direction while moving and the user has to look down to see where they are therefore ignoring the VE and his/her mission plan. Another issue with these devices is that most are not able to work out side or in a field training environment because of their size, long setup time, portability and cost. These systems generally do not meet most of the criteria of approaching a human-like locomotion system as the systems apply to much inertia on the user and then the system becomes hard to change directions or turn on a dime.

Controller / Pedal / Techniques

These techniques take the ability of your feet in to account to allow you to perform locomotion with little tethered equipment to the users. A few systems have used sensors placed in the bottom pads of user's shoes to calculate the pressure of the user's feet and where that pressure is located to perform locomotion. Foot pads are placed in the user's shoes and if the user pushes forward on the pads, their avatar moves forward. If the user simply stands on each foot, the locomotion stops. If the user puts more pressure on the back heel of the foot, the avatar will move backwards.

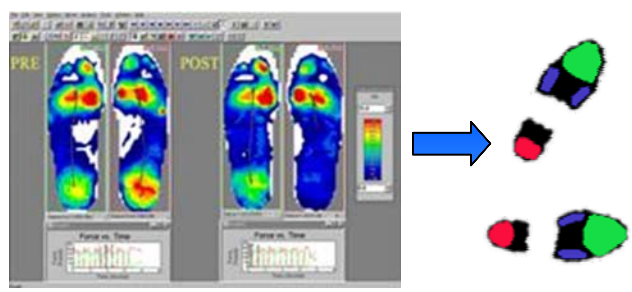

Figure 7. Foot Force Pressure Sensors

Other systems have the user sit down at a workstation and use two pedals to simulate walking, while using a two pole joystick to perform locomotion and rotational viewing. As these locomotion concepts are actually using the user's feet in the locomotion concept, they are adding more realism into the locomotion concepts.

The controller pedal technique systems appear to be the closest approaching systems to obtaining human-like natural locomotion. If the user stands up and uses minimally obtrusive means of placing sensors, then these systems may work. The fact that a foot pad is set into your shoes and can transmit and collect data is in line with a natural locomotion system. The issue is that some of these systems still allow the user to sit down and use a joystick for locomotion. Another issue is that all of the sensors have to be perfectly placed for the system to work and even if all of the sensors were calibrated, they would not stay in alignment for long. The majority of these systems use accelerometers which introduce drift into the system and the data would then be corrupted. Keeping the sensors in the correct location is crucial to these systems. With a person jumping, crawling, running, etc…in this configuration, the chances of the sensors not moving seem unrealistic.

Motion Pad Techniques

Motion pads are very common in console games and are often used to generate speed information for locomotion in the virtual environment. In some cases motion pads can also sense orientation through weight shifts or with the augmentation of an orientation sensor somewhere on the body (pelvis, head, etc).

Figure 8. Wii™ Fit Motion Platform

Other motion pad systems are available in the commercial gaming industry and could easily be redeveloped or used for research experiments. Dance Dance Revolution (DDR) was a very popular arcade game for many years and now with the home gaming systems becoming so popular, these systems are finding their way into living rooms as nothing more than plastic that you lay on the floor and each square has a sensor in it. These systems could also be developed as locomotion solutions in the near future. Motion platforms and motion controllers are becoming increasingly popular lately and could eventually be used as locomotion devices, but it is still too early in their development to say. Most of the motion platforms out today are not accurate in their movement and the user moves fairly fast over large VEs with little to no control or accuracy.

SUMMARY

In this paper, a trade study of multiple virtual locomotion systems of the past and of the present was provided in an attempt to find similarities between the systems and to find similar components for systems that may form the basic necessities of virtual locomotion. Finally, a discussion of what system(s) allow the most human-like, realistic virtual locomotion system was presented.

The similarities in all of the systems are that all are subject to accuracy errors and latency issues. The researchers hope to study each system's latency and accuracy errors in more detail in order to further define the most realistic, human-like system. The research showed that each system and every locomotion system must have two main components: speed control and steering control. Although many systems handle steering differently (i.e. waist, head and/or feet), they are common to all systems as they are the basis for all locomotion. There are also multiple systems that are attempting the same goal: realistic, human-like virtual locomotion, but many are coming from different concepts and ideas and many researchers have separate opinions about what "human-like" truly means.

CONCLUSIONS

During the course of this study, many different concepts and systems that attempt to re-create natural human locomotion in virtual environments were researched. The conditions that any locomotion system must have in order to achieve natural human-like locomotion were discovered and were discussed. The locomotion system must be as unconstrained as possible allowing users to move about as they normally would in their natural form. The locomotion system must use as many of the natural human sensations integrated into the system to give the user more of an immersive environment. Also, the locomotion system must not introduce negative training aspects to the trainees. The locomotion system must allow the user to maintain multiple postures (i.e. standing, crawling, etc…) as they would in the real world as that also increases his/her immersive feeling and allows him/her to perform more realistic poses and orientations as he/she would while performing natural human locomotion. The systems should also allow for multiple postures to occur and not be confined to only one posture for the entire locomotion period. Accuracy must be close between natural human locomotion and virtual locomotion. Latency must be decreased in the virtual locomotion system to approach natural human locomotion. Human factors must be studied and limited as much as possible to allow the user to contain his/her feeling of immersiveness. There should be no outside interference when training a soldier in a VE as to keep the soldier immersed in the VE and focused on his/her mission. Recursive techniques should be used to constantly improve the virtual locomotion system through questionnaires and user tests. New techniques are still attempting to solve the age old issue of performing virtual locomotion in order to make it seamless, realistic and human-like.

For the next phase of this study, the STTC will be partnering with companies in order to test their locomotion concepts or systems to validate their systems specifications that were provided for each system that was studied. The researchers will be inviting the companies that make the locomotion systems to participate in our upcoming experiments. The researcher's main purpose for this is to gain some experimental data from each major category of locomotion devices to use to compare the systems all on an even scale and to verify the specifications that are listed on each company's website. It was shown in Phase I that more information is needed (testing and experimentation) to truly be able to compare the different locomotion systems. A virtual locomotion test course will be developed so that all system specifications can be verified and tested for each system against its claimed specifications. Soldiers will be used to test the system vigorously and provide feedback through questionnaires which will be collected and used to compare and contrast all of the different virtual locomotion systems fairly and non-partially.

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