# Immersive Simulation to Train Urban Infantry Combat

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## *ABSTRACT*

*The key component in developing an effective virtual infantry training simulator is the user interface. Our goal is to develop interfaces that give users close to the same ability to move and coordinate actions as they have in the real world. We have developed two interfaces. Gaiter is a highly realistic body-driven interface in which the user walks in place to walk through the virtual world. With Gaiter, the user can naturally intermix a range of natural and gestural actions. An experiment comparing Gaiter with less realistic interfaces shows that a control technique that mimics a user's natural actions, while beneficial, does not immediately provide all the capabilities of natural motion. These results, along with a Marine Corps interest in lower cost, more deployable systems, have led us to develop a new virtual locomotion control. Pointman is a device-driven interface that uses a conventional dual joystick gamepad. Unlike the control mappings of a conventional gamepad, Pointman allows the user to specify direction of movement independently from the heading of the upper body, allowing the user to execute realistic tactical infantry movements such as pie-ing the corner. Pointman can also be used for teleoperation of remotely piloted vehicles, providing added separation over the vehicle's motion and view. Both interfaces derive from an analysis of action and effect that highlights the importance of providing open loop control.*

## 1.0 INTRODUCTION

The user interface is the key component in developing an effective virtual infantry training simulator. Our goal is to design and implement interfaces that give trainees close to the same ability to move and coordinate actions as they have in the real world. We have developed *Gaiter*, a full-body immersive interface in which the user walks in place to walk through the virtual environment (VE). We have also recently implemented a new control, called *Pointman,* using a conventional gamepad. Pointman has a novel control mapping that allows users to turn their body independently of their direction of motion. View control is offloaded to inertial sensors. Pointman makes it easy for the user to execute tactical movements such as pie-ing a corner, which is

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difficult to do using conventional controls. Pointman allows the user to perform training exercises following prescribed military tactics, techniques, and procedures (TTPs) using a compact, low cost interface. Pointman can also be used for teleoperation of remotely piloted ground vehicles to increase the pilot's freedom and control over the vehicle's motion and allow them to execute more effective tactical maneuvers.

To be effective, the user interface should allow the user to control his or her avatar, an articulated representation the user's body in the virtual world, in as natural a way as possible. By that we mean that users should be able to move their avatars in the virtual world as they would move their physical bodies in a corresponding real world environment. Our two interfaces represent two different levels of realistic interfaces. Gaiter is an example of *body-driven interaction* in which the user performs actions by moving his or her own body to either execute or mimic the performance of corresponding real world actions. Pointman is an example of *device-driven interaction* in which the user specifies the motion of his or her avatar through manipulating an input device. Device-driven interfaces are by far the more widely adopted approach, as can be seen in the use of joysticks, gamepads, and mouse-keyboard interfaces to direct one's avatar through a wide variety of military simulations and first-person computer games. There are many different ways of controlling one's avatar via device-driven interaction and some forms of control produce more natural motions than others. Within the specific domain of infantry simulation, we will show that controls designed to support tactical infantry movement produce better results than conventional game controls.

The benefits of virtual simulators for individual combatants are substantial. Accurate representation of the behavior of infantrymen remains a missing link in military simulations. The potential is to offer training and mission rehearsal anytime and anywhere to maintain sustainment levels and reduce skill decay. Moreover, virtual simulators are the only way to directly train scenarios that would be too costly or too dangerous to practice in the real world. Scenarios can familiarize trainees with operating in dangerous environments to help acclimate them to the stress of close confrontation. To date, virtual simulators have not been widely adopted because until recently the equipment has been too costly and system latency higher than desired. The opportunity is now here to create effective training simulators.

## 2.0 DESIGN PRINCIPLES FOR REALISTIC INTERFACES

The development of all realistic motion interfaces requires an analysis of the perceptual/action issues in the task domain to determine how actions are coordinated to produce effects. In the real world, a person performs *actions* by activating muscles to selectively apply force and move parts of the body. These actions produce *effects,* which alter the person's relationship with the environment. People balance while successively swinging their legs apart and together to move their body forward. In an analogous manner, users perform *control actions* that produce *control effects* in the virtual world. The goal is to develop interfaces that allow users to naturally coordinate motion and to execute a variety of tactical infantry movements in a realistic manner.

To aid in describing a realistic interface, we have created a list of properties derived from an analysis of how people perform real world actions to achieve effects [17]. The list contains the salient properties of both real world and control actions and effects. The list applies to both highly realistic body-driven interfaces as well as more abstract device-driven ones; the difference is in the level of fidelity of each property. The six properties help describe the nature of the match between real world actions and effects, and control actions and effects.

The first three properties only describe actions: (1) *body segments* (which body segments are involved in producing the action(s)), (2) *effort* (how much effort is required), (3) *coordination* (what is the person's ability to perform the actions in concert). The next two properties apply to both actions and effects: (4) *degrees-of-freedom and range of motion* (what degrees-of-freedom and range of motion are used in executing the action and displayed as the effect), (5) *rate and accuracy* (what is the rate and accuracy with which a motion can be performed and displayed). The last property concerns how actions and effects work together: (6) *open or closed loop control* (can the action be achieved without sensory feedback under an open loop control or is feedback required). All six properties are important but providing an open loop control where appropriate can be critical for realism. For example, people can maintain their sense of direction over short-range turns and translations in the dark [11], which is used in night operations. However, it can be a demanding property to achieve in an interface.

For body-driven interfaces, whenever possible, interaction should be *one-for-one* to provide the best match, such as when turning the body or carrying and aiming a rifle. However, not all actions can be one-for-one because the user inhabits a virtual world containing virtual objects that is larger than the immediate surroundings. In that case, we analyze the characteristics of the real world action in terms of the six properties and select a *gestural control action* that closely mimics the natural action. For the gestural control action for locomotion, a scaled mapping is used to move the avatar forward at an appropriate walking or running rate. For one-for-one control actions, actions made by the user are directly mapped into the motion of the avatar.

For device-driven interfaces, the properties describing actions and effects still apply but in a slightly different way. The properties for action now apply to the control actions that have correspondence with real world actions. These control actions should afford natural movement and tap into a user’s innate skills and abilities. They should express sufficient information to produce realistic effects in the virtual world. The properties for effect apply as they did for body-driven interfaces. Users must be able to control how their avatars look, move, and shoot with the same capabilities and limitations as people have in the real world. If motion is not expressed realistically, users develop an unrealistic expectation of what is possible.

## 3.0 GAITER

The Gaiter body-driven interface [16] allows users to walk and run in place to control their movement through the virtual world. Gaiter was originally designed to provide directional, leg-based control over virtual locomotion. The direction of motion of the user's avatar is controlled by the direction and extent of movement of the user’s legs. In this way, Gaiter operates in a body-centric coordinate frame of reference. Movements of other parts of the avatar match the user's actions one-for-one. This allows users to naturally intermix a wide range of upper and lower body movements to execute a wide range of actions. Later the Gaiter interface was extended to support full-body tracking and aiming with a rifle prop for use as an individual combatant VE simulator to train Marines in CQB for urban warfare.

In the current version of the system, the user wears an NVISOR SX model head-mounted display (HMD) from NVIS, Inc. to provide a 360º field-of-regard. The image array is 1280 by 1024 per eye with a 48º horizontal by 36º vertical field-of-view. It provides a stereoscopic image. The user is outfitted with a standard flak jacket and carries an instrumented rifle prop, a full-weight M4 replica Airsoft AEG model that transmits a signal when the trigger is pulled. The user is attached to a centering harness developed by Dr. Roger Kaufman at George Washington University, which is made of steel tubing that acts as a spring and allows the user to move no more than a foot off center. The harness turns freely and permits the immersed user to turn, walk, and run in place while staying in the center of the tracked area. The user’s body is tracked using the Vicon 612 model passive optical tracking system with 10 cameras. Tracking markers are placed on rigid objects (HMD, flak jacket, rifle, harness waist belt, and arm and shin guards) to track individual body segments.

The Gaiter interface includes one-to-one motion mapping for looking, turning, and rifle handling. For shooting, the user sees a virtual representation of a rifle co-aligned with the physical rifle and is able to look through the rendered sights to aim at the target. The location of the hit is determined from the pose of the rifle muzzle in the virtual world. In this way, the correct perceptual/action skills are used to locate the target, put the rifle on the target, and keep the rifle on the target while the shot is fired. Since the HMD shows the imagery on a single focal plane, the skill of focusing the eyes on the front sight is not trained. We blur the image of the rear sight to add realism but the degree of blurring is fixed and does not depend on user's depth of focus.

The Gaiter locomotion technique is a gestural technique that follows the design guidelines for body-driven interfaces. Walking and running in place have similarities with natural walking and running. Both allow the legs to be moved in any direction; both are compatible with other actions and permit a natural degree of coordinated action; and both operate in a natural body-centric coordinate system that allows reflexive orientation. Since turning is performed by physically stepping to turn, Gaiter provides correct vestibular and proprioceptive cues for turning. Slater, Usoh, and Steed [13] have demonstrated that the proprioception provided by a walking in place technique tends to increase subjective presence, which is a sense of actually being in the virtual space, when there is an association with an avatar. Through informal use, we have also found that users have a good sense of being surrounded by the virtual world when using Gaiter.

Gaiter has been shown to work well in a usability study testing path following tasks [14]. The results show that there was a consistent accuracy (an RMS error of about six inches) and speed (of around five feet per second) associated with walking forward down a three-foot path. Also, an assessment of simulator sickness using the questionnaire developed by Kennedy, Lane, Berbaum, and Lilienthal [5] showed that simulator sickness was not a problem. Subjects did sweat but sweating was associated with wearing a flak jacket, HMD, and stepping in place. In general, Gaiter allows the user a fair level of accuracy of control over locomotion and permits open loop control over turning. Users can coordinate actions in tasks such as looking into vistas opening up as they move around corners, holding the rifle at the ready while moving and searching for targets, and transitioning into a good firing position.

The Gaiter interface is included in a series of studies looking at the effectiveness of interfaces for training. We are conducting these studies in collaboration with the Naval Research Laboratory's Warfighter Human-System Integration Laboratory (WHSIL). These studies are part of the VIRTE (Virtual Technologies and Environments) program, which is funded by the Office of Naval Research. Preliminary results from the first experiment are below in section 3.1.

## 3.1 Comparison of Interfaces to Support Path Integration

The first experiment looked at how well subjects performed path integration tasks using one of three interfaces. Path integration is an aspect of navigation in which a person uses velocity and acceleration signals from proprioceptive and kinesthetic inputs to monitor one's position along a pathway.

The three interfaces tested were Gaiter, Rifle-Mounted Joystick, and Desktop Joystick. Each interface offered a different functionality. Gaiter allowed subjects to control the rate and direction of movement with their legs and to turn naturally. With the Rifle-Mounted Joystick, the rate and direction of translation was controlled with a thumb-joystick mounted on the handguard of a rifle prop. (The thumb-joystick was mounted on the left side of the handguard and only right-handed subjects could participate). Subjects controlled translation by pushing the thumb-joystick in the desired direction relative to where the rifle was pointed. The subject pushed the thumb-joystick forward to go forward, up to go right, back to go backwards, and down to go left. Turning was achieved by turning the body. Subjects using the Desktop Joystick controlled rotation, rate, and direction of movement with the stick. Twisting the stick rotated the view. Subjects translated their avatars by pushing the stick in the desired direction. The direction of translation was specified with respect to the view direction. A hat control tilted the image up and down and a reset button re-centered the view. All conditions included a trigger pull to mark events. The display was held constant: all subjects wore the NVISOR SX model HMD. The image moved with head motion in the Gaiter and Rifle-Mounted Joystick conditions; the image only changed under joystick control in the Desktop Joystick condition.

The experiment consisted of three tasks. The *maze task* was based on pointing to origin, which has been shown to assess path integration ability [8]. We constructed a series of passageways with two halls and an intervening turn, and asked the subjects to point back to the origin at the end. We adapted the design from a study by Klatzky, Loomis, Beall, Chance, and Golledge [6]. *Blind walking* is a version of open loop responding, which has also been shown to directly assess path integration [8]. Researchers have demonstrated that, in the real world, people have the ability to look at an object with the lights on, turn off the lights, and walk to that location, on average, with little systematic error out to about 15 m [such as in 3,7, 10, 11, 12]. The third task, *blind rotations*, compared the ability of subjects to rotate a given angle without vision. Rotation is an important component of locomotion and associated with path integration. It was included because it was easy to isolate and provided additional insights. Because the image was viewed through the same HMD, the differences in indicated direction or distance among the locomotion interfaces reflected how well the subjects used each interface and were able to calibrate to it during practice. Ideally, the subject would acquire a sense of the space while moving through the practice environments and perform navigation tasks close to how they would in the real world.

The study design was between subjects with eight subjects per group. All subjects were employed at the Naval Research Laboratory. All had good vision and all but three were male, reflecting NRL’s workforce. Their ages ranged between 26 and 35. Before the series of tasks, the experimenter demonstrated the interface to the subject and the subject had an opportunity to try it in a practice environment. The order of the tasks was the maze task, blind walking, and blind rotations.

The *maze task* was the only task performed with visual feedback throughout. The subject started the task in a 3 m square virtual room. The first hall was 9 m long; the second hall was 5 m. The turn occurred in a round room 3 m in diameter. The room where the response was given was also 3 m square. The angles of the turn were 45º, 90º, or 135º. The connecting doors closed silently behind the subject as they entered a room and blended into the wall once closed. In the last room, crosshairs appeared in the subject’s field-of-view upon reaching the center of the room, and the subject rotated his or her view to point back at the start location and pulled the trigger. The subject was then transported to the start location to begin a new trial. There were six trials with each angle repeated twice. The results of the three angle repeated measures test showed that interface was significant ($F(2, 90) = 4.47$, $p = .024$). Scheffe post hoc comparisons indicated that the Desktop Joystick interface had significantly less angular error than the Rifle-Mounted Joystick ($p = .046$). Performance with Gaiter was mixed but there was no device-by-angle interaction. Gaiter performed more like the Rifle-Mounted Joystick for the 45º turn but more like the Desktop Joystick for 90º and 135º.

We based the *blind walking* task on a design by Philbeck, Loomis, and Beall [10]. We included both direct and indirect walking as they did; however, due to technical problems, the indirect walking data were not usable although the task still served as a distractor so subjects could not pre-program their response for direct walking. Only direct walking will be described. The task took place in a large virtual warehouse that had three 1.25 m wide paths marked on the floor with a pair of colored strips. The subject faced down the center path and an object, a 5’ 11” steel plate target of a combatant, was placed on the path at one of three locations, 3.33 m, 6.66 m, or 10 m, from the start location. Each distance was repeated three times. The subject viewed the object for 5 sec until the image faded. Blind walking experiments in the real world ask subjects to close their eyes but that was impossible to confirm with an HMD so we faded the image. Only the pair of stips bounding the path was visible to the subject to help the subject maintain lateral stability. The subject was instructed to walk forward to where the object had been located, stop at that location, and press the trigger. An analysis of distance travelled along the path showed that interface was significant (F(2, 100 = 3.53), p = .047). Bonferroni post hoc comparisons indicated that the Rifle-Mounted Joystick was more accurate than Gaiter (p = .05). However, the analysis does not tell the whole story. An interesting issue was raised in the question session after the experiment. A few subjects said their strategy using Gaiter was to double the number of in-place steps they took in VE to estimate how many actual steps it would take in the real world. The results agree with this observation because the subjects travelled about twice as far as they should have. When distance travelled was divided by 2, interface was no longer significant. What appears to have happened is that the highly analytical NRL subjects interpreted their in-place steps as half steps rather than whole steps when confronted with the blind walking task.

In *blind rotations*, subjects rotated 45º, 90º, or 180º left or right with the image in the HMD faded. Each angle and direction was repeated twice. The results show a significant difference for interface (F(2, 146) = 5.72, p = .01). Scheffe post hoc comparisons showed that the Desktop Joystick was significantly worse than either Gaiter (.02) or the Rifle-Mounted Joystick (p = .036). The results confirm the advantage of an interface that provides proprioceptive and kinesthetic input for turning.

The overall conclusion suggests that when visual cues are present, subjects perform well with the Desktop Joystick. When vision is not available, proprioceptive and kinesthetic input helps, although the results are mixed. For blind rotations, actual turning used in Gaiter and the Rifle-Mounted Joystick improved performance over the rate based Desktop Joystick, which is consistent with previous research [2]. The results for direct blind walking along a path were confounded. It was expected that interfaces with proprioceptive and kinesthetic input from walking, like Gaiter, would result in better performance. But the Gaiter results contained a consistent miscalibration in which subjects interpreted in-place steps as half steps and travelled twice as far as necessary. After adjusting the Gaiter data, the results showed no significant difference between in-place walking and the two joystick conditions. Further study is needed to see if users can accept a whole step interpretation of their motion achieved through walking in place.

## 4.0 POINTMAN

Pointman is a new virtual locomotion control based on a dual joystick gamepad with added sensors. Unlike conventional gamepad control mappings for first-person shooter games, the user can control the locomotion of his or her avatar in a way that offers more effective control over a wide range of tactical motions. Pointman allows users to scan their view and rifle to cover danger areas without disrupting their motion along a path. Few controls provide this ability, yet the majority of tactical infantry movements depend upon it. It permits individuals to control realistic tactical movements in virtual simulations. Since many of these tactical movements relate to how an individual operates as part of a larger team, this new locomotion control permits realistic small unit team tactics to be simulated.

This work was motivated by an examination of the small unit infantry tactics employed in urban combat in general and building clearing operations in particular. We observed how experts perform tactical movements in the real world and using Gaiter in simulation. We compared this with the way people control the movement of their avatars with conventional gamepad and mouse-keyboard interfaces used in first-person shooter games and observed different movement strategies being used.

Tactical infantry movement involves keeping the rifle directed where you are looking while scanning for threats. "The purpose of any tactical maneuver is to allow your muzzle to cover the potential danger areas as you encounter them. Observe the three-eye principle. This means that your weapon must be oriented toward whatever it is your eyes are looking at. Wherever your eyes go, your weapon must also go. Keep the weapon in a ready position or 'hunting' attitude so that it does not obstruct your vision while you search" [15, p.22]. Figure 1 illustrates two tactical movements. Scanning is used to cover and clear danger areas, especially areas exposed as one moves around corners. In terms of perceiving the environment during locomotion, vistas open at the occluding edge of a corner as a person advances [4, p. 199]. In terms of infantry tactics, to 'pie' a corner one directs one's attention just past the corner's edge to look into the area incrementally disclosed by moving along a hallway, leading to the corner.

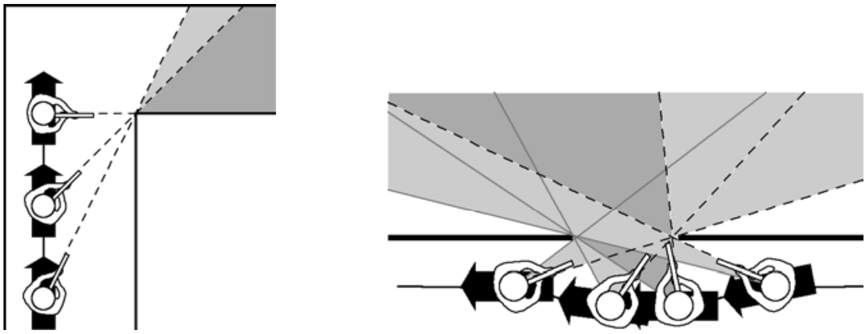

**Figure 1: Left: Turning the Heading towards a Corner while Maintaining a Straight Course. Turning the upper body to face the corner is a tactically correct way to clear a corner. Right: Pie-ing past an open doorway.**

Scanning is also used to direct one's view and rifle from side-to-side to cover one's sector of responsibility when moving as part of a team through an open area, such as a street or courtyard. Different members of a patrol team are responsible for providing front, flank, or rear security. Once something of interest is found, targeted scanning motion is used to remain focused on it.

The tactics executed with conventional gamepads place a greater emphasis on moving sideways and spiraling towards or away from points of interest, due primarily to the limitations of the control. Once that difference was clear, we saw the opportunity to develop a small footprint, low cost virtual locomotion control using conventional input devices that could better approximate the kinds of movements involved in tactical infantry maneuvers. The resulting control can benefit any application where it is useful to freely look around while continuing to move.

## 4.1 Framework for Describing Locomotion

We developed a framework for classifying real world locomotion that we used to specify Pointman and describe the performance of conventional gamepads for first-person shooter games. Although control over turning the view from side-to-side and pitching the view up and down is vital, it will be treated separately from this framework.

An important goal of virtual locomotion is to retain the ability to coordinate the motion of the avatar when we substitute control using an input device for natural ways of moving. We want motion in the virtual world to closely resemble the motions a person would make in the real world. In the case of tactical infantry movements, the specific kinds of motion are spelled out in the Marine Corps' field manual [9]. In general, when executing tactical infantry movements, the head remains in a fixed alignment with the upper body and the upper body is turned independently of the direction of movement.

### 4.1.1 Terminology

We adopt terms used in both vehicular and human navigation literature [1, 8] to describe real world locomotion for tactical movement. There are three components of motion in the horizontal plane. The head is assumed to be aligned with the upper-body as pictured in the figures.

- ***Heading**:* Angular direction the upper-body faces.
- ***Course**:* Angular direction the pelvis translates.
- ***Displacement:*** Distance the pelvis translates.

The first two components specify orientation with respect to a fixed reference direction and the third specifies distance travelled. The *alignment-offset* is the angle between the course and heading. The angle between the direction of a step (course) and the direction of the upper body (heading) determines the kind of step being taken (Figure 2).

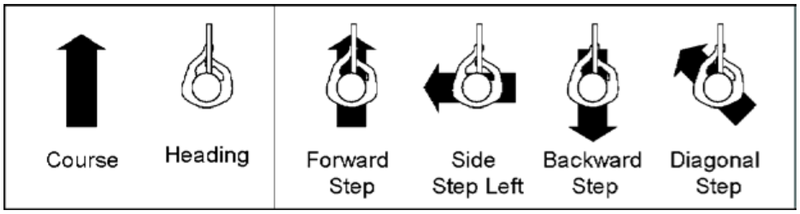

**Figure 2: Illustration of Basic Terms: Here the direction of aim indicates the heading. The angle between the course and heading determines the kind of step being taken.**

### 4.1.2 Classification of Human Locomotion

The following classification illustrates the kinds of motion a person can make while walking or running in the real world in terms of how course and heading vary. In the figures, all kinds of motion involve moving along a path. A person can also turn his or her heading without translating by twisting the pelvis or stepping to turn in place, but that is not depicted.

***Steering Motion**:* Course and heading remain co-aligned while moving along a path (Figure 3). Steering motion can be used to move directly towards a stationary or moving target and to follow a route marked out on the ground by facing forward along the trail.

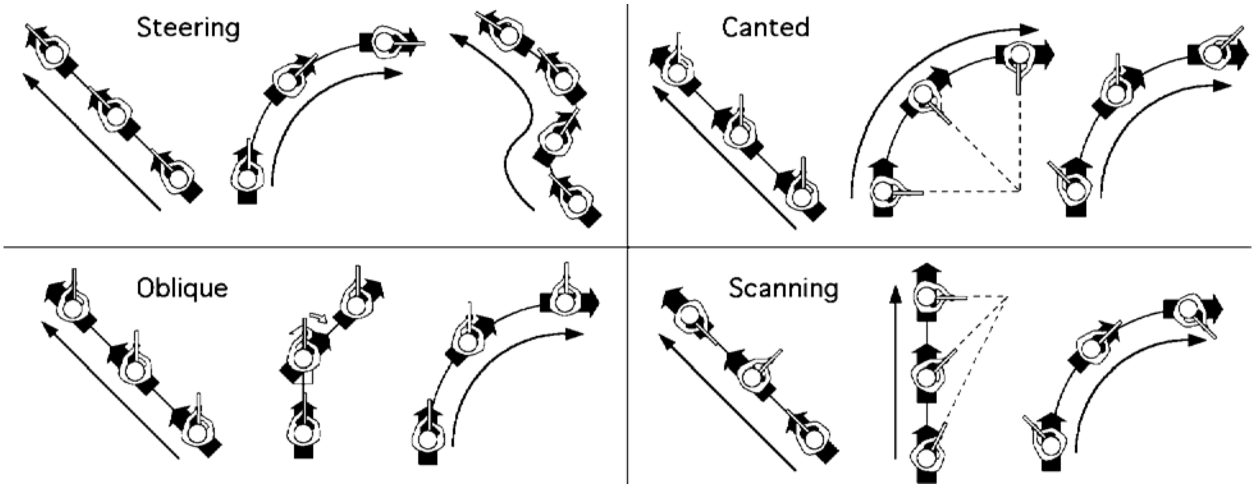

Figure 3: Examples of Steering, Canted, Oblique, and Scanning Motion.

***Canted Motion**:* Course and heading maintain a fixed alignment-offset while moving along a path (Figure 3). Steering motion is a sub-class of canted motion.

***Oblique Motion**:* Heading remains in a fixed direction while moving along a path (Figure 3). Notice that moving along a straight path with a fixed alignment-offset qualifies as both canted and oblique motion, so the classes partially overlap.

***Scanning Motion:*** Heading is free to turn separately from the course while moving along a path (Figure 3). Scanning motion can be used to search from side-to-side while moving or to remain directed towards a stationary or moving target, while traversing a straight or curved path. Scanning while traversing a curved path is the only case where the heading and course vary independently.

## 4.2 Conventional Gamepad Controls

Gamepads are widely used to control virtual locomotion in many first-person shooter games, especially on game consoles. Modern gamepads provide a pair of thumb-joysticks used to change the course and heading of the user's avatar. The controls are applied in a fairly standard manner.

The right joystick turns the course and heading together at a rate set by the amount of lateral deflection. (Deflecting this joystick forward and backward pitches the view up and down, but is not part of locomotion.) We call the right joystick the *steering joystick* (Figure 4, right). Pushing the steering joystick to its full leftmost extent turns course and heading together to the left at a maximum angular rate (degrees per second). Pushing it only partially over to the right turns them to the right at a slower rate.

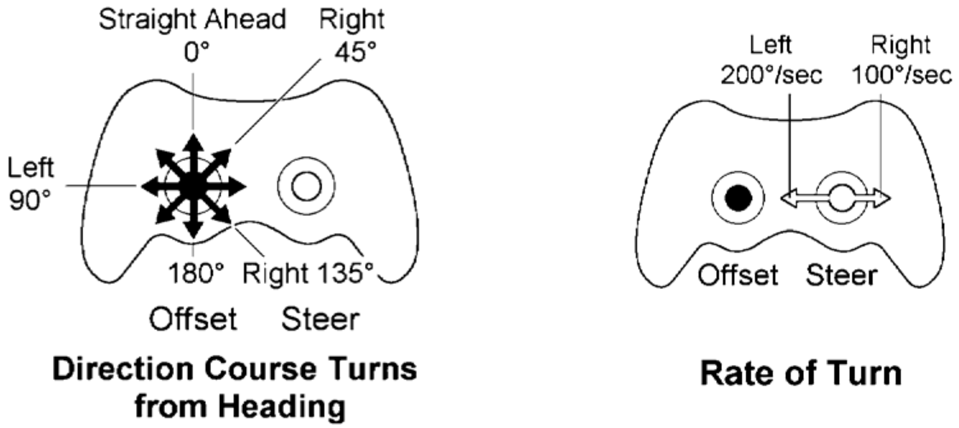

**Figure 4: Conventional Joystick Controls. Right: Rate control over steering. Left: Directional control over course-offset.**

The left joystick sets the rate of displacement by the amount of deflection of the joystick and the direction of the course relative to the current heading by the angular direction in which it is pushed. We refer to the left joystick as the *offset joystick* because it controls the alignment-offset between course and heading (Figure 4, left). When the offset joystick is engaged, the course is redirected and the heading remains unchanged. Figure 2 above showing examples of alignment-offsets in terms of stepping patterns illustrates the patterns: Pushing the offset joystick forward directs the course forward (forward step); pushing the joystick left or right moves the course to the side relative to the heading (side step); pushing the joystick back directs the course back (back step); and pushing the joystick on the diagonal produces a diagonal course relative to the heading (diagonal step). Pushing only the offset joystick without engaging the steering joystick moves the avatar in a straight trajectory in the specified direction; deflecting the steering joystick without engaging the offset joystick turns the avatar in place.

In summary, the offset joystick redirects the course without altering the heading. The steering joystick controls the rate at which the course and heading turn together. Therefore, we categorize conventional gamepad controls as a course-offset, rate-based steering control.

### 4.2.1 Executing Different Classes of Motion

The steering and offset joysticks are manipulated (control action) to move the user's avatar through the virtual world (control effect). Because of the way the joystick actions control course, some classes of motion are easier to achieve than others. Moreover, redundant control over course gives rise to a multitude of different ways of entering the same final course.

*Steering motion* requires deflecting the steering joystick while pushing the offset joystick forward. The view changes as the heading turns and the avatar advances along the trail. It is a closed loop control because the user relies on visual feedback to determine the extent of rotation and translation. Both steering and displacement are rate controlled.

*Oblique motion* is accomplished using only the offset joystick. Heading remains fixed in the current direction because no steering occurs. The user enters the course simply by pushing the offset joystick in the desired direction without need of visual feedback. Therefore, oblique motion is controlled in an open loop manner. The user continually feels the current direction of the course offset.

*Scanning* while following a straight path is difficult using conventional gamepad controls (Figure 5). The steering joystick must turn the heading to scan, but the course turns along with it (Figure 5, left). To follow a straight path (Figure 5, right), the offset joystick must *counterturn* to cancel out this rotation of the course (Figure 5, middle). It is difficult to balance the two forms of turning since one joystick is controlled by rate and the other by direction. Without knowing how far the steering joystick changes the direction, the user does not know where to point the offset joystick to counter it. Scanning while following a curved path is even more difficult using such controls.

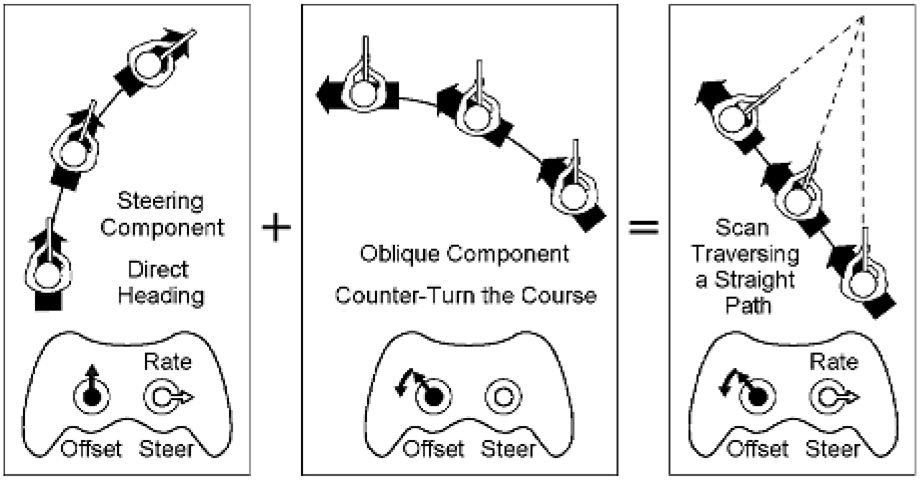

**Figure 5: Course-Offset Control – Turning only the Steering Joystick Executes Steering Motion. Activating only of the course-offset joystick executes oblique motion. Combining these particular actions executes scanning while traversing a straight path. Note the complex interaction between the two components of motion required to maintain a straight course.**

Conventional gamepad controls favor visually directed motion because rate-based steering relies heavily on visual feedback. Both canted and scanning motions allow the avatar to turn to face a target while moving along a path. Users compensate for the weakness in executing scanning motion by relying heavily on canted motion. They adopt a control strategy called *targeted canted motion* in which the heading is constantly turned toward the target while the alignment-offset of the course and heading remains fixed in order to steer them together as a unit. Targeted canted motion is performed by deflecting the steering joystick while holding the offset joystick in a fixed direction. A family of spiral trajectories emerges by doing so (Figure 6). A sophisticated user can smoothly transition between these trajectories to achieve even more complicated paths. The term *strafing* is used in the gaming community to denote oblique motion, shooting while moving obliquely, and the form of targeted canted motion just described. *Circle-strafing* is the tactic of circling a target while facing toward it.

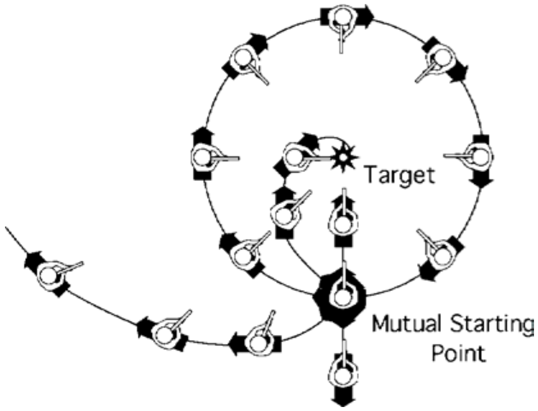

Figure 6: Examples of Targeted Canted Motion.

## 4.3 Pointman: a new directional control

Pointman uses a conventional dual joystick gamepad in a new way. The joystick's control over virtual movement is modified to direct course and heading in a more factored way that favors scanning. View control, including pitch, is offloaded to orientation sensors.

With the new approach, the user pushes the steering joystick (Figure 7, right) in the angular direction of the desired path of motion. This provides directional control over turning the heading and course together, as opposed to the conventional rate control. The offset joystick (Figure 7, left) now directs how far the heading turns away from the course. We call this a heading-offset control. When only the heading-offset joystick is operated, the heading turns to follow the direction in which the joystick is pushed. When there is no displacement, the heading rotates, turning the avatar in place.

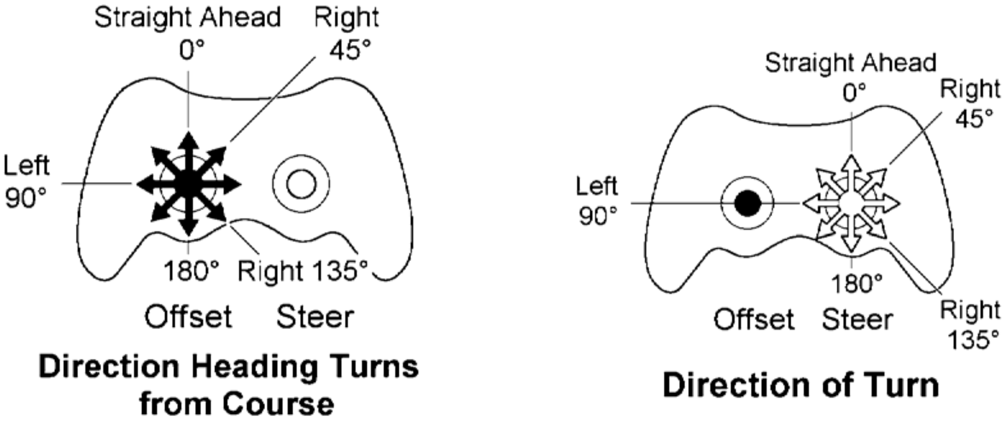

Figure 7: Heading-Offset Pointman Controls. Right: directional control over steering.
Left: directional control over heading-offset.

A technique called *panning* is applied to limit the rate at which the heading rotates under directional control. In its raw form, an abrupt turn would instantaneously jump the heading to a new direction and a smooth turn would rotate the heading at the rate by which the joystick turns. Panning is set to a maximum rate commensurate with how fast a human can actually turn his or her body.

We call this a fully directional control, because both the steering and offset joysticks express course and heading as the angular direction in which the joysticks are pointed. Directional control over both joysticks allows users to better coordinate the two because they are now directed in a similar way. Moreover, users continually feel the alignment of the two orientations and can move their avatar in an open loop manner. This is an ongoing sensation, just as with actual locomotion where people feel the alignment between their leg motion and the direction of their upper body.

Before either joystick is engaged, both the course and heading initially correspond to the direction in which the avatar's upper body faces. Once engaged, the angle of the steering joystick indicates the direction of the course relative to this initial direction. The angle of the heading-offset joystick indicates the heading relative to the course. The initial direction provides a fixed reference frame until the joysticks are released. The avatar's final heading becomes the initial direction for the next round of movements.

We categorize Pointman as a heading-offset, fully directional control. With this approach, both joysticks can turn the heading, but the steering joystick also directs the course. Steering is directed with respect to the environment in the same way regardless of how the heading is varied by the offset joystick. This provides consistency of use.

We recommend offloading control over displacement to sliding foot pedals that mimic a person’s foot motion during locomotion and preserves the open loop nature of walking. The two pedals are mechanically coupled so that one goes forward as the other goes back. The absolute displacement of the coupled pedals is scaled and applied to displace the avatar along the course. Scaling is done on a moment-by-moment basis and can be started or stopped at any instant.

The preferred method for view control is to attach a three degree-of-freedom inertial sensor to an HMD that reports all three viewing angles (yaw, pitch, and roll). In this case, the view rotates naturally as the head is turned. Alternatively, the tracker can be attached to a gamepad. Users can rotate their view by tilting the gamepad with their hands. This approach works well with fixed screen displays, ranging from desktop monitors to surround screen projection systems. A low-end approach is to allocate a pair of (shoulder) buttons on a gamepad to provide rate control over raising and lowering the pitch of the view, but that is more difficult to use.

### 4.3.1 Executing Different Classes of Motion

When individually applied, the steering joystick directs steering motion (Figure 8, left) and the heading-offset joystick directs scanning while traversing a straight path (Figure 8, middle). Other motions are achieved by combining the steering and heading-offset joysticks in different ways. Scanning while following a straight path is easy using Pointman (Figure 8) because directing heading does not redirect the course. The two components of motion are independent and combine in a straightforward manner.

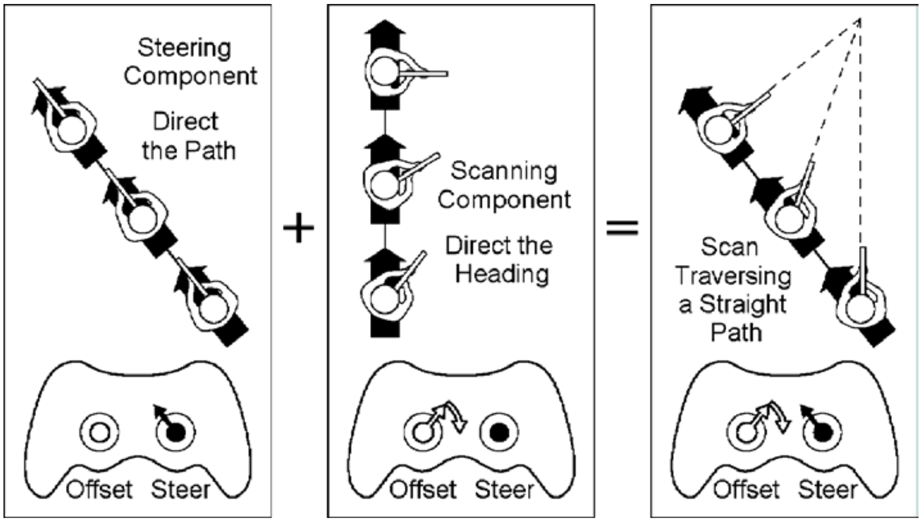

**Figure 8: Heading-Offset Control - Activating only the of steering joystick executes trailing motion. Activating only the offset joystick executes scanning moving straight ahead. Combining these particular actions executes scanning while traversing a straight path. Foot pedals apply a constant rate of displacement in all cases. Note how the two components of motion make independent contributions to the resulting motion.**

Moving obliquely requires extra work to maintain a forward heading. The steering joystick is turned to go in the desired direction while the offset joystick is counterturned to maintain the heading. Counterturns can be executed smoothly by revolving both joysticks by an equal amount in opposite directions (a revolving counterturn), or abruptly by pushing them in opposite directions, symmetrically about the median plane of the gamepad (a direct angle counterturn). This can be done without visual feedback and maintains the open loop nature of Pointman. On balance, oblique motion is easier to execute with the course-offset control, and scanning motion is easier to execute with the heading-offset control.

## 4.4 Comparing Pointman to the Conventional Gamepad

A review of the literature on infantry tactics shows that scanning, looking over top of the rifle for threats while moving, is a defining element of tactical movement. But scanning is difficult with the vast majority of device-based virtual locomotion controls which are course-offset, such as the conventional gamepad controls, mouse-keyboard interfaces, and interfaces in which a joystick is mounted on a rifle prop to control the course while the user turns wearing an HMD. In all these interfaces, turning the heading redirects the course, disrupting the user's ability to follow a path while scanning. As a result, it becomes very difficult to execute realistic tactical maneuvers.

In contrast, Pointman adopts a heading-offset control to allow the user to easily scan to look side-to-side or fixate on a target while traversing a path in the environment, corresponding more closely to recommended tactical movements. The steering joystick is manipulated in the same way to traverse a given path no matter how the offset joystick alters heading. This independence offers additional advantages. The constancy makes it easier to follow paths regardless of how users direct their heading, and it reinforces the open loop approach because fewer control variables need to be sensed and acted on. With practice, users can execute a variety of real world tactical infantry movements in a simulator using either an HMD or fixed display.

Solving the tactical movement problem led to a control that allows users to freely scan their heading without redirecting the course. This result can benefit any application where it is useful to freely look around while continuing to move.

## CONCLUSION

In summary, we have described two interfaces for virtual infantry training simulators. Gaiter is a high-end body-driven interface that allows the user to apply and intermix a range of natural and gestural actions. Pointman is a new device-driven interface that allows the user to independently direct the course and heading to move about in the virtual world. Both allow the user to execute the recommended tactical infantry movements. The two interfaces can be applied by different users participating in a common networked simulation. Each trainee has an avatar that reflects his or her actions, allowing team members to coordinate their actions. The advantage of Gaiter is that it engages the user's entire body in the simulation and requires correct manipulation of a realistic rifle prop. Pointman uses the gamepad for turning and moving. Realistic weapons handling is traded-off to provide a low-cost, small-footprint system that can easily be set-up and operated anywhere.

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