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Coupling Virtual Reality and Motion Platforms for Snowboard Training

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***Abstract*—This paper proposes a snowboard simulation system that mitigates the risks of snowboarding while allowing for realistic beginner training. The system uses a passive motion platform with tension bands that return the platform to equilibrium when the user is not applying force. This allows the user to make manual changes to board position as they would on a snowy hill. These manual changes in board position are fed into the simulator, and the user experiences visual cuing as to changes in their simulated position, velocity, and acceleration. This snowboard simulator is the first to feature manual yaw with full range of motion, allowing users to train on essential beginning techniques like "the falling leaf" and paving the way for the future development of simulation of advanced techniques necessary for navigating advanced terrain.**

***Keywords*—Virtual Reality, Sports, Simulation, Motion Platform, HTC Vive**

1. INTRODUCTION

Immersive environments like CAVEs, have long been used for training but often limited to niche markets. By contrast, today's consumer-grade virtual reality setups offer cost and performance levels for mass market appeal; headsets, hand-controllers, and motion capture are readily available for a wider range of training applications. Many sports are physical, employ special equipment, and must be performed in dedicated areas. Snowboarding is one example and serves as a case study for this paper. Beyond graphical fidelity, a motion platform is needed; the snowboarder's egomotion must physically train for balance and yaw. Such a case study serves to yield more insight on the overlap of virtual reality and robotics through the coupling of immersive graphics, egomotion, and motion control.

Snowboarding's popularity in the past decade has grown. However, recent studies report that 67% of all snowboarding injuries occur within the first seven days of trying the sport. Beginners have a high frequency of lower arm and wrist injuries. Additionally, regardless of skill, over a half of snowboarding injuries are due to falling [1]-[3]. Current virtual reality sports trainers like STRIVR [4] serve athletes by analyzing their response time and performance [5]. Hence, they are not well-suited for casual users who value injury-prevention training. Towards such users, home-based trainers [6] have emerged for balance-based sports. For snowboarding, Park and Moon employed pressure tile sensors under the user's feet to track center of mass [7]. In their system, a fully actuated motion platform moves beneath the user, independent of user control. However, this platform does not let the user manipulate the snowboard's position.

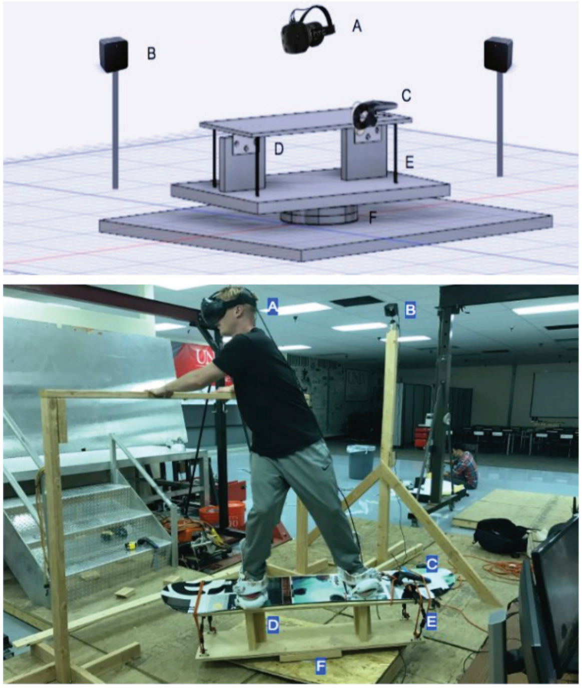

Fig. 1. Headset (A) displays the simulation to the user. IR sensors (B) independently track movements of the headset and a controller (C) attached to the top of the motion platform. The motion platform has 2 DOF's: roll via hinges (D) under the top platform and yaw via the swivel joint (F) between the bottom two platforms. Four tension bands (E), one in each corner, run vertically from the top platform to the middle platform.

Current training systems do not fully account for the snowboarder's dynamic manipulation of board position. Such egomotion allows for speed and directional control. To address this gap, injury-prevention training, and to gain deeper insight on the overlap of virtual reality and robotics, the system in Fig. 1 was developed. Section 2 presents technical design requirements and the trainer's underlying dynamics; Section 3 describes the resulting system design; Section 4 gives the testing and evaluation results; and Section 5 concludes.

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TABLE 1
ANALYSIS OF EXISTING SNOWBOARDING SIMULATION MOTION PLATFORMS

Name	**Dynamic Behavior**	**Degrees of Freedom**	**360 Degree Yaw Range**
Proposed Platform	passive	roll, yaw	yes
Alpine Surfer - Snowboard Simulator	passive	yaw	no
SkyTechSport Simulator	actuated	roll, yaw	no
Moon and Park 2013 Snowboard Trainer	actuated	roll, yaw, pitch	yes
Futuretown 5D TotalMotion	both	roll, yaw, pitch	yes

2. REQUIREMENTS AND DYNAMICS

Table 1 is a summarized trade study of snowboarding trainers. Technical design requirements were identified for unmet needs and for injury-prevention training. First, the user should be secured to a constrained but passive platform. As such, the user cannot rotate into contact with the ground. This constraint eliminates arm injury risks. Furthermore, being passive allows for balance training. Second, resistive forces are needed for leg-muscle training. Tension bands are thus employed that pull the platform towards equlibrium position. Headset and motion capture gives the snowboarder feedback on his inputs to the platform. Finally, snowboarders often perform 360-turns. As such, the platform is required to yaw circularly.

Many snowboarding techniques are difficult to practice in simulation. Maneuvers like *the falling leaf* require over 180 degree range of yaw to perform. Such basic and essential maneuvers demand egomotion and hence an actuated platform. As shown in Fig. 2, the maneuver is as follows. First, the snowboarder has his board perpendicular to the slope's downhill direction, and at a large roll angle. Second, the snowboarder varies yaw periodically; the board's nose points downhill at some angle for a few seconds and then reverts back to being perpendicular. Third, the snowboarder mirrors this sequence of actions with the board's tail pointing downhill for a few seconds. Finally, the snowboarder alternates between leading with the board's nose and tail; he shifts his weight to remain balanced as the board goes through acceleration changes. Many maneuvers demand egomotion training with a full-range of yaw, especially more advanced ones that involve moguls and obstacles.

The virtual reality simulation moves the viewer's frame of view according to several dynamic equations. The equations are defined according to a coordinate system that is rotated from the world frame such that the Z-axis is always perpendicular to the slope, pitched at angle θ as shown in Fig. 3. To model the snowboarder's motion, the equations take into consideration gravity and both the normal and frictional forces between the board and snow. These forces are calculated as functions of board roll α, board yaw γ, and slope angle θ. The equations also include coefficients for board response B, gravity G, and friction μ that have been tuned with user feedback to achieve a more realistic simulation. Board response B refers to a combination of factors such as board stiffness, rider mass, edge sharpness, and board shape that affect how quickly and completely the board transfers impulses from the user to the slope. Because the simulation targets beginners, the simulated snowboarder's motion has been constrained such that they are always in contact with the slope, and the slope remains at a constant pitch of $\theta = 10$ degrees. The dynamic equations define acceleration as follows:

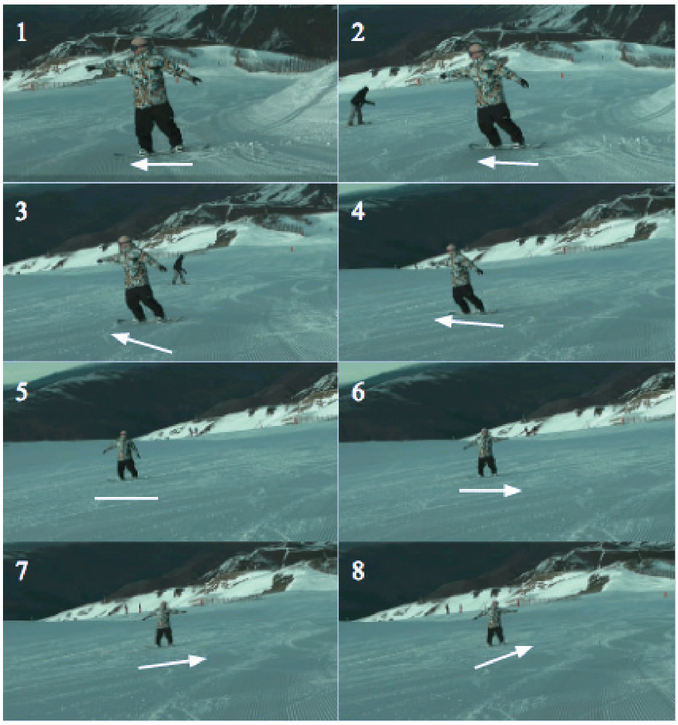

Fig. 2. Snowboarder performing ”the falling leaf”. The board starts perpendicular to the downslope direction (1), yaws towards parallel (2 and 3), then swings back (4) to perpendicular (5) before repeating the maneuver with yawing to the opposite side (6-8).

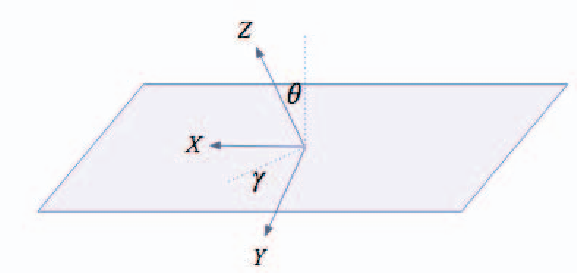

Fig. 3. Z-axis is defined as being perpendicular to the plane of the slope with an angle θ from vertical. The Y-axis always points in the downhill direction, and the X-axis runs laterally relative to the the downhill direction. γ is the yaw angle, measured as angular displacement from the downhill direction.

$$X^{"} = B\alpha \qquad (1)$$

TABLE 2
COEFFICIENTS TUNED FOR REALISTIC SIMULATION

Coefficient	Value
Board Response (B)	2
Gravity (G)	9.8
Friction (μ)	.075

$$Y^{''} = G\sin(\theta) - \mu BG\cos(\theta)\sin(\gamma)\sin(\alpha) \tag{2}$$

$$Z^{''} = 0 \tag{3}$$

In articulating the snowboarder's acceleration as a function of board position (roll and yaw), the equations use sinusoids to manage changes in direction. The initial angles of zero for roll and yaw are defined by the board position in which the board points in the downhill vector and is parallel to the plane of the slope. Negative values are used for roll rotations with vectors pointing uphill and for yaw rotations with rotation vectors pointing up perpendicular from the slope.

3. SYSTEM DESIGN

For effective training, the system must allow the athlete to practice some combination of movement, timing, and decision-making [3]. This paper's snowboarding trainer accomplishes this in two ways: a passive 2 degree-of-freedom (DOF) motion platform with resistive tension and visual cueing via virtual reality goggles.

During operation, the user stands on the top plane of the motion platform. The top plane is attached to vertical supports via hinges that allow for ± 45 degree range of motion. This allows for realistic board positioning while constraining rotations that would bring the user into contact with the ground and threaten injury. The passive nature of the motion platform allows for balance training methods proven to reduce injury. In a basic snowboarding turn, the snowboarder applies torque to the board perpendicular to the roll axis, increasing the pressure on one edge of the board as it pushes deeper into the snow. The snow on the slope applies increased frictional and normal forces on the burrowing edge of the board and the rider experience changes in acceleration. On the groomed slopes beginners most frequently encounter, the evenly packed snow resists the action of the snowboarder's torque, subtracting from the impulse. The tension bands in the motion platform emulate this sensation, holding the board parallel to the ground when no torque is applied and delivering a resistive force when the board is displaced from equilibrium. The tension bands also act as a mechanical lowpass filter for user roll input. The torque from the tension bands during platform displacement is much less than the torque users apply during intentional platform manipulations, while being large enough to dampen small perturbations that arise in error. The virtual reality component of the simulation helps the user practice their decision-making and timing while delivering visual simulations of changes to acceleration produced by user changes to board position. The visual simulation is accomplished with a virtual reality game in which the goggle frame of reference is positioned on a computer animated snowy slope. The acceleration of the goggle frame is a function of the user's manual manipulation of the board position, as described in Eq. (1), (2), and (3). As shown in Fig. 1, Infrared (IR) sensors positioned above and beside the motion platform track the goggles as the user moves their head. The virtual reality (VR) goggles adjust their display based on the IR data on the orientation of the user's head. Users can freely move their head to view the snowy slope around them as they move down the slope with acceleration independent of point-of-view (POV). By manually adjusting the roll and yaw of the motion platform below them, the user changes the direction and magnitude of the acceleration they experience in the simulation. Visual cuing helps the user reinforce the cause-effect relationship between manipulations of board position and changes in trajectory [7].

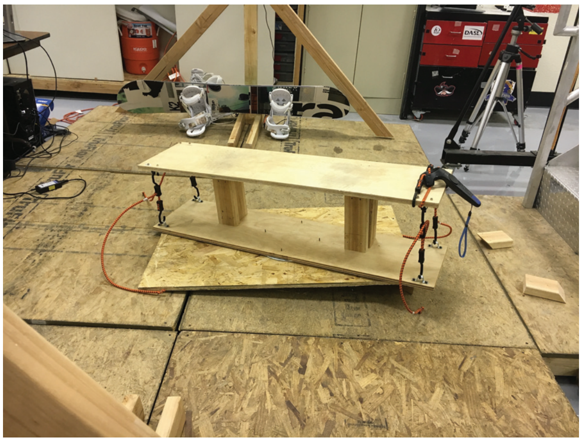
Fig. 4. The platform design allows users to attach their personal equipment to the top such that users can train using the same board, bindings, and boots that they use on the mountain.

The motion platform features the 2 DOF most common in snowboard simulations: roll and yaw (see Table 1). Most existing simulators constrain the range of motion for roll and yaw to ± 15 degrees [7] [8] [10]. For realism, balance training, and injury-prevention training, this paper's trainer provides ± 45 degrees yaw and ± 360 degrees yaw. The motion platform is designed such that tension bands attached to the top plane of the platform resist torque applied by the user and return the top plane to a roll of 0 degrees when the user centers their balance. This resistive tension simulates the normal force of the snow that resists board rotation. The tension bands are attached above the swivel joint in the motion platform, such that the user does not experience resistance from the bands when varying yaw. 360 degree range of yaw is accomplished by letting the upper platform rotate unrestrained relative to the base. This full range of motion around the yaw axis allows beginners to practice essential techniques like *the falling leaf*

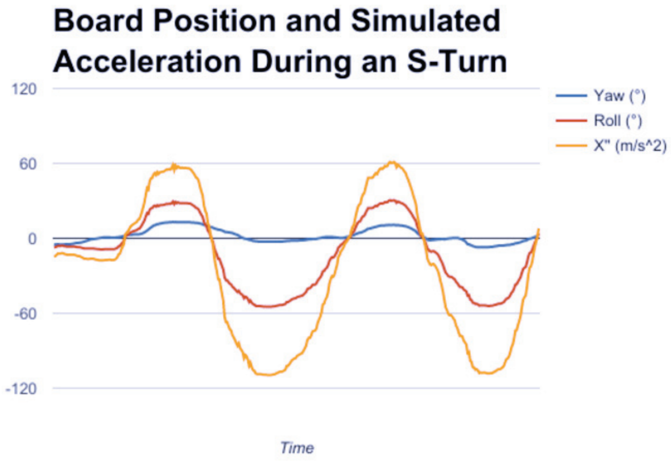

Fig. 5. Yaw and roll values from accelerometer and gyroscope data from HTC Vive controller and IR sensors are plotted with the resulting lateral acceleration rendered in the virtual reality simulation.

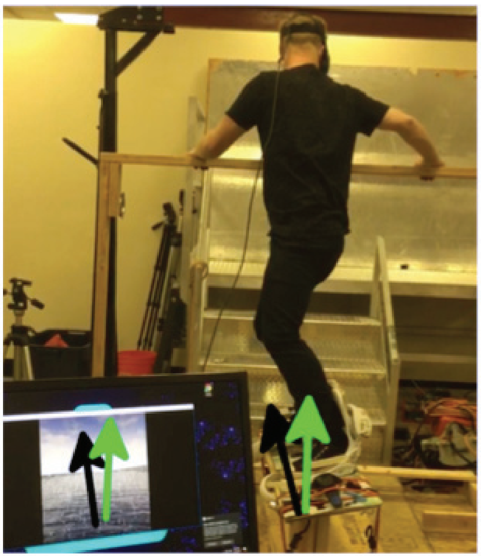

Fig. 6. User demonstrates slight roll and yaw angles.

as well as more advanced techniques like switched stance.

Recent advances in virtual reality technology made the implementation of this project much less time and resource intensive than expected. For this project, the HTC Vive was used for sensing and VR output with no electrical adaptations of the sensors necessary. A single HTC Vive controller was attached to the top plane of the motion platform, two HTC Vive IR sensors were positioned above and beside the motion platform, and the user wears an HTC Vive headset. The HTC Vive controller uses an accelerometer, gyroscope, and infrared tracking to read position and rotation data and send it to a desktop computer for simulation processing. The HTC Vive headset also tracks changes in position and rotation and updates the user's simulated VR POV as they *look around*. The premises of implementation involved in this virtual reality simulation can be applied to other applications for consumers, broadening the access of use of virtual reality technologies.

4. EXPERIMENTAL RESULTS

This paper's motion platform is designed for snowboarding fidelity. The pitch angle is constant at a small downward angle similar to that found in a beginner's bunny slope. The platform can be manipulated into every position that a beginner would experience in controlled practice of instructional techniques, with 360 degree range of yaw being a unique key feature. Figs. 6-8 show user manipulation of the motion platform while running the virtual reality trainer. In Figs. 6 and 7, arrows show the direction of the user's simulated acceleration (black) as well as the direction of the downhill vector (green). One notes in Fig. 6 that the user has negative roll and yaw positions. The position of the board in Fig. 6 corresponds to the user experiencing acceleration in the negative X and Y directions within the simulation (left picture). With very small α and γ , changes in downhill acceleration are negligible. This is consistent with Eq. (2).

Fig. 7 shows a more exaggerated position of the board position relative to Fig. 6. As the user gives a deeper yaw and roll, the simulated position of the user within the simulation will change more dramatically. In Fig. 7, the user experiences increased lateral acceleration and decreased downhill acceleration relative to Fig. 6. This response is consistent with what a snowboarder would experience on a real mountain slope. The deeper the yaw and roll position is, the more the user would be affected by the normal and frictional forces from the snow, accelerating the rider across the mountain and producing some downhill deceleration. Fig.8 shows the user performing a full turn and the simulation rendering over that time. Transitioning between positions yields a continuous change in simulated position, velocity, and acceleration. Within the simulation, physics updates, sampling, and rendering occur at 90 Hz. The user navigates the virtual slope, changing their acceleration with user input as dictated by Eq. (1), (2), and (3). The simulation's fluid transitions and tight responsiveness to user input accomplish a highly realistic and effective simulation for practicing essential beginner techniques, such as *the falling leaf*, and more in a safe and controlled environment.

5. CONCLUSION

Consumer-grade virtual reality systems give wider access for non-professional users. This also opens the door to identify overlaps between virtual reality and robotics. This paper's case study on snowboarding serves to gain such insight. Given that snowboarding demands egomotion, a motion platform was described. This actuated platform is coupled with virtual reality hardware for snowboarders to practice maneuvers and injury-prevention training. Experimental results reveal high motion and visual fidelity for such practice and training. Envisioned future work would implement additional degrees-of-freedom and tension cables to practice jumps and flips. Robotically programming these degrees-of-freedom could also

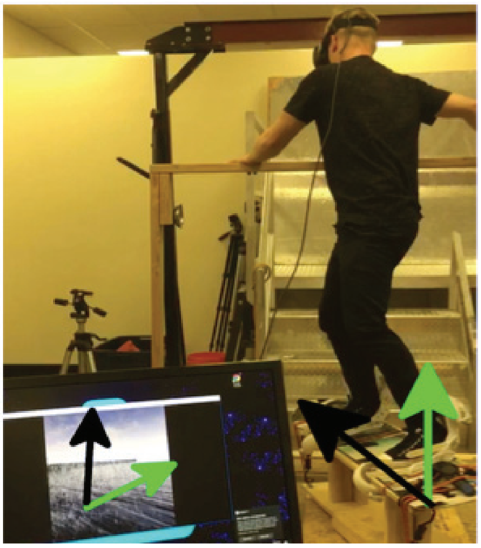

Fig. 7. User demonstrates high roll and yaw angles.

give a *template* of maneuvers for the snowboarder to practice and instill into his *muscle memory*. Data feedback could also be used to track training progress to cultivate better coordination, timing and decision-making. The net effect of this case study was to demonstrate the efficacy of coupling motion platforms with consumer-grade virtual reality hardware to achieve egomotion training with broad appeal.

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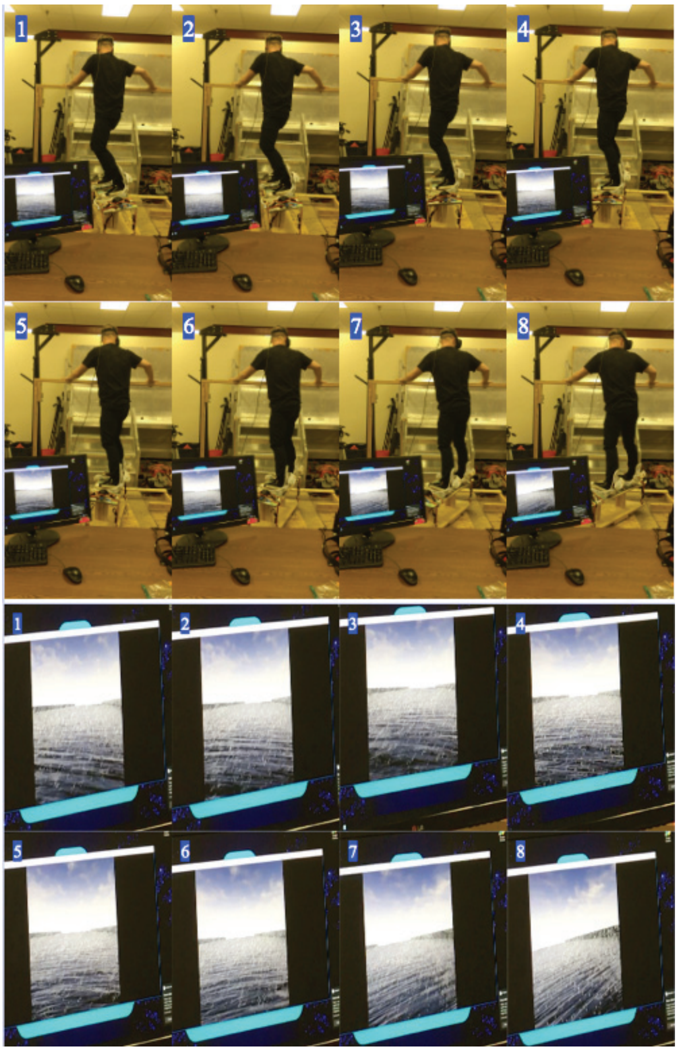

Fig. 8. As the user manipulates the motion platform through a turn, the VR headset display renders acceleration of the viewer's point of view.

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