Description

Title

Inverted Sensorimotor Training System and Method

1. Field of the Invention

The present invention relates to sensorimotor skill training systems, and more particularly to a **system and method for training hand-eye coordination and visual-motor adaptation under inverted visual conditions**. The invention spans physical and computer-implemented embodiments (including virtual reality and augmented reality platforms) designed for **gamified rehabilitation, skill development, and therapeutic interventions** in vision and neuromotor domains.

2. Background of the Invention

Experimental psychology and neuroscience have long studied human adaptation to **inverted vision**. It is known that when a person's visual field is turned upside-down (for example, by wearing prism goggles that invert the retinal image), initial performance in simple tasks deteriorates dramatically, but over time the brain can partially adapt to this altered sensory input[1]. Classic studies showed that subjects wearing inversion goggles **initially exhibit large motor errors** and disorientation, followed by gradual improvement with practice[1]. However, even after prolonged continuous exposure (e.g. 8 days), performance can remain unstable and not fully normalized[1], indicating that adaptation under inversion is effortful and may involve both conscious and implicit strategies. Additionally, wearing such devices initially induces a range of motion sickness-like symptoms (e.g. dizziness, vertigo, nausea, miscoordination)[2], underscoring the challenge of inverted visual feedback.

Conventional **upside-down goggles** (also called *invertoscopes*) have been used primarily as laboratory instruments to demonstrate perceptual adaptation or to induce specific physiological effects[3][4]. Prior art devices include optical inversion helmets or goggles dating back to the 19th and 20th centuries, such as those by George Stratton and Theodor Erismann, and later designs like Dolezal's prism helmet[5][6]. These devices, while proving the concept of adaptation, were often bulky, heavy, or limited in field of view[7][8]. They generally lacked any interactive training content beyond the wearer's everyday tasks, and did not incorporate modern feedback or data capabilities. In essence, **no comprehensive training system** existed to actively guide users through exercises under inverted vision, track their progress, or make the experience engaging.

Meanwhile, **virtual reality (VR)** and related technologies have emerged as powerful tools for sensorimotor training and rehabilitation. VR-based training systems have been applied to stroke rehabilitation, balance training, and other motor learning contexts[9], leveraging immersive environments and real-time feedback to stimulate intensive practice[10]. Gamified rehabilitation devices (e.g. game-based hand therapy systems) have demonstrated that providing real-time feedback and engaging challenges can improve outcomes in neurologic recovery[11][12]. However, prior VR rehabilitation systems have focused on **conventional visual feedback** or augmented feedback (such as exaggerating errors or guiding movements), rather than deliberately inverting or distorting the visual input. None have specifically harnessed **optical inversion as a training modality**.

The potential benefits of training under inverted vision are suggested by research: forcing the brain to reconcile unexpected sensory-motor mappings may strengthen adaptive capacity and error-correction mechanisms[13]. *Motor adaptation* is driven by error feedback – the difference between expected and actual outcomes – which the nervous system uses to update motor commands for future attempts[13]. Inverted vision greatly increases such errors initially, providing rich feedback for the brain to learn from. With structured practice, users can learn to compensate for the inversion (e.g. by adjusting movement directions), a process that can reveal fundamental properties of sensorimotor learning[1]. There is evidence that adding other sensory cues can aid this learning; for instance, **haptic feedback** given alongside inverted vision can improve tracing accuracy by signaling errors to the user[14]. However, excessive or poorly tuned haptic input might overwhelm the user[15], suggesting that any supplementary feedback should be adaptive and used judiciously.

In summary, there remains a need for an **integrated training system** that not only provides an inverted visual experience but also guides the user through specialized exercises to accelerate adaptation, uses modern sensors (like eye trackers and motion trackers) to personalize training, and employs gamification techniques to motivate consistent practice. Such a system would be valuable for general skill enhancement (e.g. improving spatial reasoning and coordination), as a **therapy for visual or neurological disorders** (by leveraging neural plasticity under altered sensory conditions), and even as an engaging training game. The present invention addresses these needs by combining optical inversion apparatus or simulated inversion in VR/AR with interactive tasks, feedback modalities, and adaptive algorithms to create a **comprehensive inverted sensorimotor training platform**.

3. Summary of the Invention

Overview: The invention provides a **sensorimotor training system** that inverts the user's visual input and challenges them to perform tasks, thereby training the brain to adapt to altered visual-motor relationships. The system can take multiple forms – a purely physical setup, a VR-based digital system, or an AR (augmented reality) implementation – all utilizing the core concept of visual inversion and feedback-driven learning. The training experience is enhanced with **gamification features** (such as scoring, levels, and competitive challenges) and augmented with **multi-sensory feedback** (visual, haptic, and audio) to keep users engaged and informed of their progress.

Embodiments: In one embodiment, the system comprises **inversion goggles** (optical headwear containing prisms or mirrors that flip the incoming image upside-down) worn by the user, and a **handheld pointer device** (e.g. a laser pointer or stylus) that the user uses to interact with targets in the real environment. The user attempts tasks such as touching or illuminating targets on a wall while viewing the world inverted through the goggles. Another embodiment uses a **virtual reality headset** to simulate an inverted visual environment: the VR software renders the scene rotated 180° or otherwise transformed so that up is down (and left-right may also be reversed), and the user's motions (tracked via controllers or motion sensors) are mapped into this inverted visual frame. A further embodiment employs an **augmented reality mode**, for example using a tablet or smartphone's camera feed; the live video from the device's camera is inverted in real-time on the display, and virtual targets or overlays are added on the screen. The user interacts via the touchscreen or by moving the device to aim at targets in the inverted view. In all embodiments, the **difficulty of tasks** can be adjusted adaptively: initially, tasks may be made easier (larger or static targets, slower pace) and as the user improves, the tasks become more challenging (smaller or moving targets, time limits, etc.).

Adaptive Feedback and Sensing: A distinguishing feature of the invention is its use of **sensors and adaptive algorithms** to monitor user performance and adjust training parameters. For example, an **eye-tracking subsystem** can be integrated (either built into a VR/AR headset or as a standalone unit in goggles) to measure where the user is looking, how long it takes them to locate targets, and indicators of visual strain (e.g. blink rate or pupil dilation). These metrics are used by the system to infer the user's level of difficulty or engagement and to trigger adjustments – such as slowing down the introduction of new targets if the user is struggling, or increasing difficulty if the user is performing exceedingly well. The system also optionally includes **wearable haptic feedback devices** (like a glove, wristband, or vest with vibratory motors). These devices provide tactile signals corresponding to performance events: for instance, a gentle buzz can cue the user if they are deviating from a path they are supposed to trace, or a pulse of vibration can reward a successful hit on a target. Research has shown that strategically applied haptic cues can help users correct their movements under inverted vision[14], improving error awareness, while ensuring not to overload the user[15].

Gamification: To promote engagement, the system employs **gamified training modules**. The user may earn points for completing tasks, achieve levels or badges for reaching certain milestones, and receive real-time feedback such as scores or accuracy metrics displayed on a screen or heads-up display. In the VR/AR embodiments, a **persistent virtual canvas** is maintained – this means that the user's cumulative actions (for example, lines drawn while tracing shapes, or marks where their laser hits landed) can be saved and displayed across sessions. This allows the user to visualize improvement over time (e.g. seeing that their traces are becoming closer to the target path session by session) and adds a creative element to the training (the "canvas" could become a piece of art or record of progress).

Modes of Operation: The invention supports multiple modes including: - **Training Mode:** a guided mode where tasks are presented in a structured progression, with possibly tutorials or assistive cues. In training mode, the system might, for example, overlay arrows or hints in the VR view to help the user initially, and gradually remove assistance as they adapt. - **Test Mode:** a mode to evaluate the user's sensorimotor performance without assistance. In test mode, the user might be asked to complete a standard set of tasks under inverted vision as a way to measure their adaptation level (e.g. measuring how quickly and accurately they can perform). -

Competition/Multiplayer Mode: a mode in which two or more users can train simultaneously in a competitive or collaborative game. For instance, two users each wearing their own system (either in the same location or remotely via network connection) can attempt to hit targets, trace a path, or solve a maze under inverted vision, and the system will record their times or scores. A **real-time scoring and feedback loop** informs each user of their performance relative to others – this could be via a scoreboard display, auditory announcements, or visual cues (e.g. in VR, seeing a ghost avatar of the opponent). This friendly competition serves to motivate users to improve and adds a social dimension to the training.

Therapeutic and Specialized Applications: The disclosed system is not limited to healthy users or generic skill training. It can be tailored for **clinical therapies**. In one variant, the system is used for treating **amblyopia** (lazy eye) by engaging binocular vision under novel conditions. For example, the system can present an inverted view to the dominant eye while the amblyopic (weaker) eye sees a normal or differently processed view, compelling the brain to rely more on the amblyopic eye's input. Alternatively, the system can simply be used as a fun visual-motor exercise to improve convergence, focus, and usage of the amblyopic eye (possibly by adding tasks that require depth perception or alternating eye use). For **stroke rehabilitation**, the system can help patients relearn coordination by essentially "resetting" their learned mappings—under inversion, even the unaffected side must learn anew, which can encourage neuroplastic changes. The tasks can be designed to emphasize use of the affected limb (for instance, a patient with a weak right arm might use that arm to control the pointer or controller in tasks, exercising it in the process of adaptation). Because the system logs detailed performance data (such as how smooth or accurate movements are, reaction times, error rates), therapists can monitor progress objectively. Another application is in **neurodevelopmental training** for children with conditions affecting coordination or spatial processing (such as developmental coordination disorder or certain autism spectrum conditions). The engaging, game-like nature of the system can encourage these individuals to practice visual-motor skills. The inversion aspect challenges the brain and could potentially enhance cognitive flexibility and sensory integration by forcing the child to interpret unusual sensory input and still accomplish goals.

Overall, the invention marries the concept of **inverted visual perception** with modern interactive technology to create a unique training tool. By providing comprehensive support – from physical hardware to software algorithms – the system enables users to experience and conquer the upside-down world in a safe, controlled, and even entertaining manner. Through consistent use, a user's **sensorimotor adaptation** is expected to improve, which may carry over to improved coordination and perceptual skills in normal conditions as well (once the goggles are removed or the view returned to normal). The system's **data-driven adaptive approach** ensures that the training remains at an appropriate difficulty level, maintaining a state of challenge that is neither too frustrating nor too easy, thus optimizing learning and neuroplasticity.

4. Brief Description of the Drawings

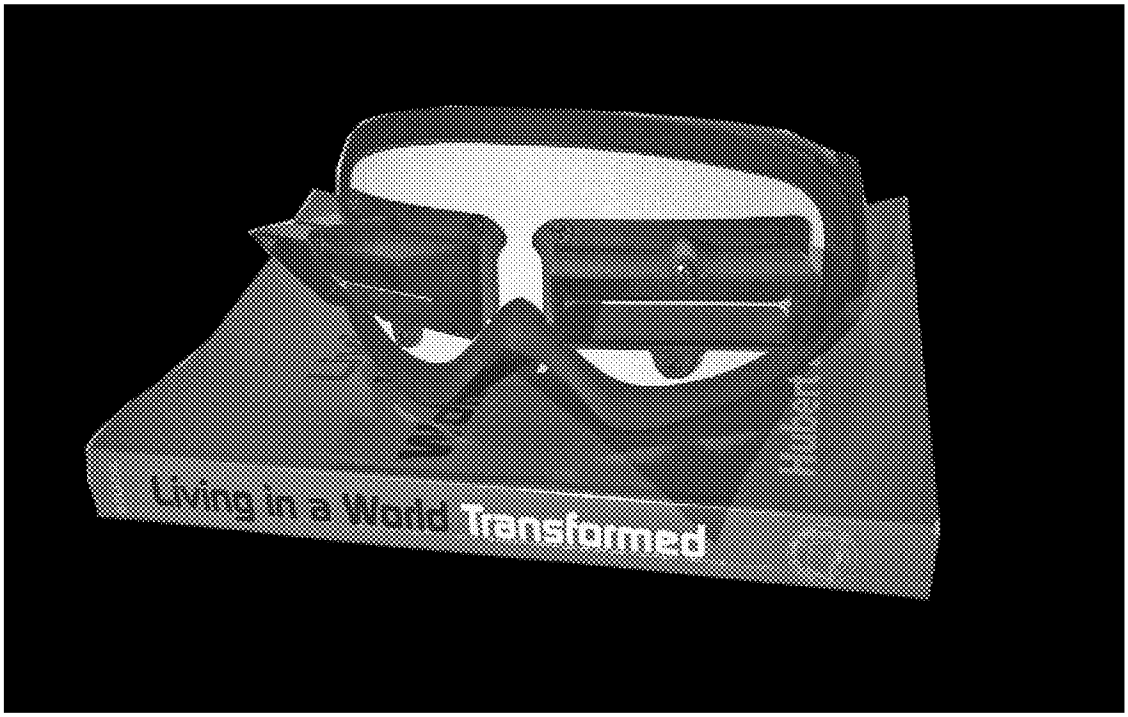

FIG. 1 illustrates a physical embodiment of the inverted sensorimotor training system. A user (wearer) is shown wearing inversion goggles and using a handheld pointer (for example, a laser pointer) to aim at a target on a wall. The goggles contain optical elements that flip the user's view of the wall target upside down, making the task of pointing counter-intuitive. *(In the depicted example, the goggles are a prism-based device mounted on a headstrap, providing a wide field of inverted vision.)*

FIG. 2 is a block diagram of a virtual reality (VR) training system embodiment. It schematically shows the components including a VR headset worn by the user, motion tracking sensors (such as hand controllers or gloves), a computing device running the training software, and interconnections between these elements. The figure highlights data flows: for instance, the user's head and hand motions are tracked and fed into the software, which renders an inverted visual scene to the headset display, and processes feedback and scoring.

FIG. 3 illustrates an augmented reality (AR) implementation using a mobile device (such as a tablet or smartphone) with a pass-through camera. The device's screen displays an inverted live video of the real environment with overlaid virtual elements (e.g., a target or drawing guide). The user interacts via the touchscreen, for example tracing a shape that appears over a real object or tapping on virtual targets that appear at real-world locations on the inverted view. This figure shows the user holding up the tablet to view a scene (such as a wall with a drawing) and using their finger to trace according to the AR game's instructions.

FIG. 4 is a flowchart depicting an **adaptive difficulty adjustment process based on eye-tracking and performance metrics**. The flowchart outlines steps such as: capturing the user's gaze patterns (fixation duration on targets, etc.), measuring performance indicators (like error rate or time to complete a task), comparing these metrics to predefined thresholds or trends, and then adjusting parameters of the next task (for example, making the target larger or slower if the user struggled, or smaller/faster if the user succeeded easily). Feedback loops in the flowchart illustrate how the system continuously updates the challenge level to optimize the user's learning curve.

FIG. 5 shows a schematic of a **multiplayer competitive training scenario**. Two users are depicted (either side-by-side or remotely connected) each with their own inverted training setup (which could be VR, AR, or physical). A central server or communication link connects the two, synchronizing a common task (for example, a race to complete a maze or hit a sequence of targets). The figure includes a representation of a scoreboard or real-time feedback display that both players can see, updating their scores or times. Arrows indicate the **feedback loop**: each user's performance influences the game state (e.g., who is in the lead), which is fed back to motivate the players. In a cooperative variant, the figure could show both users contributing to a shared task (like jointly drawing an image on the persistent canvas), with the system providing collective feedback.

5. Detailed Description of Embodiments

The following detailed description provides various embodiments and examples of the inverted sensorimotor training system. These examples are intended to illustrate the principles of the invention and how different configurations can be realized. It is to be understood that the scope of the invention is not limited to these specific examples, and modifications or substitutions of components can be made without departing from the spirit of the invention.

Physical Embodiment: Inversion Goggles with Pointer Device

In one embodiment, the training system is implemented using **physical inversion goggles** and a corresponding interaction apparatus. **FIG. 1** (as shown in the drawing and the accompanying image) depicts this setup. The inversion goggles (100) are a head-mounted device worn over the user's eyes. They contain one or more optical elements, such as **prisms** or mirrors, arranged to flip the incoming light vertically (and in some designs, horizontally as well). For example, a common design uses a pair of right-angle prisms per eye to invert the image that reaches the retina[16]. When the user wears these goggles, the view of their surroundings appears upside-down and left-right reversed. Objects in front of the user, like a target (102) on a wall, will appear at the opposite location in the visual field (e.g., the target on the upper left wall appears to the user at lower right). The goggles are designed to fit securely (using straps) and block out external light that bypasses the prisms, so that the user's brain receives only the inverted visuals (to prevent any "cheating" via normal peripheral vision[17]). Modern materials allow these goggles to be lightweight and comfortable, avoiding the excessive weight issues of older designs[6].

The user holds a **pointer device** (110), such as a laser pointer emitting a visible light dot, or a stick/stylus that can physically touch targets. In a basic configuration, training might involve the user standing a certain distance from a wall and attempting to point the laser dot at a series of targets (102) marked on the wall (these targets could be bulls-eye patterns, shapes, letters, etc., depending on the training game). Because the user sees the wall inverted, moving the pointer in a given physical direction results in the dot appearing to move in the opposite direction in their inverted view. For instance, if the user tries to move the dot upward towards a target that appears “above,” they must actually move their hand downward in real-world coordinates. This creates a sensorimotor mismatch that the user must learn to overcome through practice and recalibration of hand-eye coordination.

The system may include **sensors to track performance** in the physical setup. One approach is to use a camera (120) mounted facing the wall to detect where the laser dot lands. The camera can be connected to a computing unit (150) which runs software to log the dot’s position relative to the target, measure accuracy, and compute a score. In one implementation, the targets on the wall could be made of a photosensitive material or embedded with light sensors, allowing the system to directly detect a “hit” when the laser is on target. Simpler implementations might rely on the user or an instructor to note whether the target was hit, but for an interactive gamified system it is preferred to have automated sensing.

During use, the physical embodiment can present various **exercises**: - **Static target aiming:** Targets appear (or light up) one at a time in different positions. The user must quickly aim the pointer at the active target. The system times how long it takes and whether the hit was accurate. This can be turned into a score (faster and more accurate earns more points). - **Sequencing tasks:** A sequence of targets lights up in a particular order (possibly forming a pattern or shape). The user must hit them in that order. This trains predictive movement under inversion as the user has to move the pointer from one to the next, dealing with inverted directions continuously. - **Tracing tasks:** Instead of separate targets, there may be a solid line or shape drawn on the wall (e.g., a large zig-zag or curve). The user tries to trace along the line with the laser. Any deviation from the line can be measured (via the camera tracking the dot). This task is particularly challenging as it requires continuous fine corrections under inverted feedback, and it provides rich error information. - **Balance and coordination tasks:** The user could be asked to walk along a line on the floor or throw/catch a ball while wearing the inversion goggles. These exercises go beyond just the pointer and train whole-body coordination. The system can incorporate such tasks by instructing the user and possibly using additional sensors (like motion sensors on the body to capture gait data). These variants illustrate that the invention can encompass broader activities, but in the core embodiments we focus on hand-eye tasks with pointers or similar instruments.

To enhance the **gamification** in the physical setup, the system may include auditory cues (a sound that plays when a target is hit or missed), a **score display** (e.g., a small screen or even a projector that shows the current score/time to the user), and levels of difficulty. Difficulty in the physical context can be adjusted by: - Changing target size (smaller targets are harder). - Changing target distance or location (requiring larger movements or more precision). - Introducing moving targets (e.g., targets that shift position or maybe a moving light the user must chase on the wall). - Reducing available time (forcing faster reactions). - Only allowing use of a specific hand (to train off-hand coordination, etc.).

Adaptive adjustments: The physical embodiment can include an **adaptive module** as well. For example, if the system’s camera and software detect that the user consistently misses high (a common initial error might be always overshooting or undershooting due to inversion), the system can provide feedback: perhaps an audio message like “Try moving the pointer lower than you think you need to,” or flash a hint on a connected display. As the user improves and starts hitting targets more accurately, the system may speed up the rate at which new targets are presented to keep the user challenged (maintaining a desired error rate that is neither 0% nor too high, for optimal learning). The adaptive logic in the physical case can be somewhat simpler than VR, but the principle is the same.

The physical embodiment may be used under supervision (for example, by a therapist or trainer) or standalone by the user. All performance data (scores, timings, error patterns) can be saved to the computing unit (150) or uploaded to a cloud database for later analysis. This is important in therapeutic settings: a clinician could review the data to see how the patient's coordination is improving from session to session, similar to how progress in conventional therapy is tracked.

Virtual Reality (VR) Embodiment: Immersive Inverted Training Environment

In another embodiment, the system is implemented virtually using a **VR headset** and associated hardware. This embodiment leverages the flexibility of computer graphics to create a controlled inverted world and can incorporate more complex game-like scenarios that are not possible in the simple physical setup.

Hardware Setup: Referring to FIG. 2, the VR embodiment includes a head-mounted display (HMD) (200) worn by the user, which has internal screens (one for each eye) to present stereoscopic images. The HMD is connected to or contains a processing unit (210) that generates the virtual environment. The user's head movements are tracked by built-in sensors (gyroscopes, accelerometers, and/or external tracking cameras) so that the virtual camera view can be updated accordingly (allowing the user to look around in the virtual world). The key modification here is that the **virtual camera is inverted**: the rendering software applies a 180-degree rotation about the appropriate axis (or an equivalent transform) to the scene. In practice, this means if the user in the real world looks up by tilting their head up, the virtual scene is rendered as if they looked down. Similarly, looking left in reality might result in the view panning right in VR (depending on if horizontal inversion is also applied). The inversion can be configured to be **vertical-only** (flipping top-bottom) or **vertical and horizontal** (a 180° rotation which is equivalent to both upside-down and mirrored), or even other transformations (such as a 90° rotation for a different kind of disorientation training). By default, a full 180° inversion of the view is used to replicate the classical upside-down vision scenario.

The user also utilizes input devices (220) for interacting with the virtual environment. These can include: - VR **hand controllers** (handheld devices with buttons/joysticks and motion tracking, common in VR kits) which can serve as virtual pointers or hands. - Instrumented **gloves** that track finger motions (to allow more natural pointing or drawing). - **Eye-tracking cameras** inside the headset (230) as part of an advanced configuration, enabling the software to know where the user is looking on the virtual screen. - Potentially **body trackers** or additional sensors if full-body tasks are involved, though in many cases focusing on hand/arm motion is sufficient.

Virtual Environment and Tasks: The software presents a virtual scene to the user. This scene can be highly customizable. For instance, it could simulate a simple room with a large canvas or whiteboard on one wall (for drawing tasks), or an open space with floating objects as targets, or even a fantastical game environment (e.g., an upside-down floating island world where the user has to navigate and collect items). The key is that everything the user sees is inverted in orientation.

A typical scenario might be a **persistent canvas** environment: The user finds themselves in front of a large virtual canvas (like a painting easel). They have a virtual paintbrush or pen (controlled by their hand movements via the VR controller). The system might ask them to draw specific shapes or follow templates on the canvas. Because of the inversion, moving the controller up makes the brush go down on the canvas, etc. The user's strokes can be recorded. Over multiple sessions, the canvas can retain the previous strokes faintly (as a "ghost" image) to show improvement – for example, on Day 1 their attempt to draw a circle was wobbly and off target; by Day 5 their circle overlaps more correctly with the template. This **persistent canvas** feature helps visualize progress and also adds a sense of continuity to the training (the user might feel they are contributing to a growing artwork or record).

Other VR tasks can include: - **Target shooting or hitting:** virtual targets appear in 3D space (like balloons or orbs) that the user must reach for or point at with a laser beam from their controller. The inversion makes judging directions tricky at first. Scoring is based on how many targets are hit within a time limit. - **Maze or navigation games:** the user could control an avatar or just their viewpoint through a maze where up/down controls are swapped. This trains higher-level spatial planning under inversion. (E.g., pressing joystick "forward" moves them backward in the virtual world, etc., if we choose to invert controls in addition to view). - **Object manipulation puzzles:** pick-and-place tasks (like stacking inverted appearing blocks) or catching objects that fall "upwards" due to gravity inversion in the simulation. The system can simulate physics in the inverted frame to create challenging puzzles that require adapting one's intuitive physics understanding. - **Multiplayer mini-games:** In VR, multi-user interaction is possible in the same virtual environment. For example, two users might play a tetherball-like game where they bat a virtual ball to each other, except each sees the world upside down, making timing and direction judgment difficult – a competitive but fun exercise.

Adaptive Difficulty in VR: The VR software continuously monitors performance metrics. These include: - Task success rate (e.g., targets hit vs missed). - Time taken to complete tasks. - Precision of movements (like how closely a drawn line followed the intended path). - Head and hand movement patterns (erratic or smooth). - **Eye-tracking data** (if available): where the user is looking. For instance, if the user is not looking at the target or is scanning excessively, it might indicate confusion. Gaze fixation duration on the correct target could indicate the moment they identify it. A longer delay in looking at the next target could mean the user is slow to reorient.

The adaptation algorithm can use these inputs to adjust difficulty in several ways: - If the user is doing too well (e.g., consistently hitting targets quickly), the system can **increase difficulty**: make targets smaller or appear for shorter durations, increase background distractions, or even increase the degree of inversion if initially it wasn't full (for example, some training might start with only a 90° rotation and gradually move to 180° inversion). - If the user is struggling (e.g., very low hit rate, or very jagged drawing lines indicating loss of control, or eye-tracking shows a lot of erratic gaze), the system can **reduce difficulty**: slow down the task pace, give only one target at a time instead of multiple, increase target size, or provide additional cues (like an arrow showing which direction they should have moved). - The system can also give **real-time feedback** based on these metrics. For example, if eye-tracking notices the user is not looking at the correct quadrant of the canvas for a while, the system might highlight the target briefly or flash it to draw attention (gently guiding their gaze back). Or if the user's hand is drifting wrong, perhaps a subtle haptic buzz can be triggered (if haptics are active) to cue them as was noted earlier.

This adaptive approach ensures the user remains in a **productive learning zone** – challenged enough to drive adaptation but not so overwhelmed that they give up. It's a feedback loop (depicted conceptually in FIG. 4): measure performance -> classify difficulty -> adjust parameters -> next task -> repeat.

Eye-Tracking Utilization: Incorporating eye tracking in VR (element 230 in FIG. 2) provides another layer of adaptation. For example, the system could detect *when* the user identifies the correct target by their gaze. A metric like **gaze response time** (how quickly their eyes move to a new target after it appears) can be monitored. As the user adapts, one would expect this time to decrease since they become better at predicting where things are in the inverted view. The system can log this metric. If progress stalls, maybe the system introduces a brief on-screen guide (like a line connecting current focus to the next target) to help retrain their search strategy. Eye tracking can also measure **pupil dilation**, which correlates with mental effort or stress. A significantly increased pupil size during a task may indicate that the task is mentally strenuous – the system might use that as an input to not increase difficulty further until the user acclimates (this is a more experimental use, but within the scope of possibilities). Some research even suggests correlating physiological measures to optimize training difficulty in real time.

Immersive Feedback and Haptics: The VR environment can deliver rich feedback: - Visual: scoreboard displays, progress bars, or congratulatory effects (like virtual confetti on success). - Auditory: spatial audio cues (like a sound coming from where the next target will be, to hint at location, which is an interesting aid under inversion) or just positive/negative sounds. - **Haptic feedback:** If the user is using controllers with vibration motors, the system can pulse the controller when, say, a target is successfully hit (a rewarding jolt), or if the user's virtual hand collides with a wall or object in the wrong direction (a warning buzz). If the user wears a haptic glove or suit, more advanced cues can be given (like a tap on the left shoulder if they should shift left, etc.). The wearable haptic feedback units (240) can connect wirelessly or wired to the VR system and are controlled by the software's feedback module. The synergy of haptics with inverted vision training is notable: A study showed that providing touch cues can help an inverted-vision user stay oriented on a line tracing task[14]. Our system can modulate these cues – for instance, initially the user gets continuous low-level vibration when on the correct path ("guiding rail" feedback) which is gradually removed as they improve to encourage independent adaptation.

Data and Analytics: The VR software logs detailed data each session: trajectory of movements, times, errors, gaze patterns, etc. These can be compiled into **analytics reports**. For example, after each session the user (or a clinician) can see a dashboard: "Today you hit 15/20 targets in the first attempt. Average targeting error was 5 cm, down from 8 cm yesterday. Your reaction time to new targets improved by 20%. You experienced 3 instances of confusion where you looked away from the target area (likely due to inversion), which is an improvement from 10 such instances in the first session." This kind of feedback not only is motivational but also helps diagnose where the user still has trouble (e.g., always mixing up left-right movement perhaps). The analytics module (250) can employ machine learning to detect patterns in the performance data over many sessions – for instance, clustering the types of errors the user makes. If the AI notices the user consistently overshoots in the vertical direction but not horizontal, it might adjust the training to focus more on vertical control.

Augmented Reality (AR) Embodiment: Passthrough Video Inversion on Mobile/Headset

The AR embodiment bridges the gap between the physical and virtual by overlaying inverted visuals onto the real world. FIG. 3 represents one example using a **tablet device (300)**. In this setup, the user holds a tablet such that its back camera (310) faces the scene of interest (e.g., a wall with targets or a piece of paper with a drawing task). The system software on the tablet captures the live video feed from the camera and applies a transformation to invert it before displaying it on the tablet screen (320). The user looks at the tablet screen to see the world beyond it, but now inverted.

In essence, the tablet acts as a window or **see-through AR display** but with a manipulated view. Because tablets and phones have high-resolution screens and cameras, the latency can be low enough for real-time movement. The user can move the tablet around to look at different parts of the scene; the view will correspondingly pan, but always inverted relative to reality.

Interaction via Touch Interface: The user can use their finger or a stylus on the touchscreen to interact with the content. For example: - If a target is visible on the screen (say a virtual balloon overlaid on a real background), the user tries to tap it. Because the view is inverted, the visual location of the balloon is on the opposite side of where it actually is relative to the user's hand movement. Tapping accurately thus requires compensating for that. - For a tracing task, the tablet could show an outline over the real object (like a line drawn on a physical paper). The user traces on the screen along that line. Since the video is inverted, their finger's movement relative to the actual paper is inverted. - In a drawing scenario, the user could point the tablet at a blank paper or whiteboard and draw on the screen; the software could translate that into actual drawing via a connected device or just record it virtually. The inversion would make controlling the drawing tough, similarly training coordination.

AR Glasses Variant: Instead of a tablet, one could use an AR headset with pass-through cameras (e.g., devices like the Microsoft HoloLens or Magic Leap, or newer VR headsets with color pass-through like Meta Quest Pro). In those, the user wears the device and sees the real world captured by cameras and shown on internal displays. Our system would intercept that pass-through feed and invert it. The advantage of a wearable AR is that the user's hands are free to do tasks naturally (like actually writing on paper while seeing it inverted through the headset). This requires robust tracking to overlay any virtual guides.

In both cases, AR allows **blending virtual objects with the real world**. The system can, for instance, superimpose virtual targets on real physical locations. A practical example: Stick some physical markers (QR codes or AR fiducials) on a wall or table. The AR software recognizes them and knows where to put virtual content. The user wearing the AR sees an inverted view of their room with, say, virtual balloons anchored at those marker positions. They can physically reach out and pop the balloons (if using hand tracking or a controller) or use a laser pointer toy and the system detects the hits through computer vision. This merges physical and virtual play and can increase engagement (the room can be turned into an inverted playground).

Adaptive Features in AR: Many of the adaptation techniques from VR apply to AR. Eye tracking might be available on some AR headsets to monitor gaze. Performance is tracked similarly (did the user tap the correct spot, how far off, how long it took, etc.). Difficulty can be adjusted by adding more virtual distractions in the scene or by making the UI hints less obvious.

One unique aspect in AR is managing **real-world reference**. Because the environment is real, the system might incorporate real objects into tasks. For instance, a user could practice pouring water into a glass while wearing an AR headset that inverts their view – a daily activity that becomes tricky. The system could overlay a virtual marker to show the desired water level, etc., and track spillage via a sensor. While somewhat beyond the core, it shows the extensibility: training under inversion can be applied to daily activities, not just abstract tasks, and AR is a great way to do that because it lets the user see the real world (albeit altered) and interact with actual objects, while still under the system's monitoring.

Multiplayer AR: Two users in the same room could use their phone/tablet AR viewers to see inverted versions of the space and maybe see each other's avatars or pointer cursors on the screen. They could then engage in competitive tasks like a scavenger hunt: the system generates virtual objects in the room that each user must find and tap on their device, inverted. The system can track who finds what first and tally points. Because it's AR, they are actually moving in the real room (which is safe as long as they are careful, since they do see reality albeit flipped). This adds a physically active component which can be good for therapy (e.g., encouraging a stroke patient to move around and reach out more, under playful conditions).

Haptic in AR: Users can wear the same haptic devices (like a vibrating wristband) to get cues. E.g., if looking in the wrong direction for a target, a vibration on the left or right arm could hint "the target is that way" (like a compass). In an AR training for spatial neglect therapy (a stroke condition), one could imagine vibrotactile cues nudging attention to the neglected side. Since prism glasses are known to help neglect[18], an AR inversion might similarly be beneficial, and adding haptics may reinforce scanning of the affected side.

Adaptive Difficulty Control Using Eye-Tracking (FIG. 4 Flow)

This section describes in more detail the **adaptive control logic** as shown in FIG. 4. The process can be implemented in software as a loop during training:

1. **Present Task:** The system presents the next exercise or level to the user (e.g., a new target appears in VR or AR, or the user is asked to trace a specific shape).
2. **Capture Sensor Data:** As the user attempts the task, the system captures various data streams:
3. The user's input performance (hits, trajectory, errors).
4. Eye-tracking data: for each target, the system logs whether the user looked at it immediately or searched around; it may compute metrics like *time-to-fixation* (how many milliseconds after target onset until gaze lands on target) and *fixation stability* (how steadily they gazed or if they kept losing it).
5. Physiological or behavioral data if available (heart rate, head movement intensity, etc., though these are optional).
6. **Evaluate Performance:** The system compares the performance to criteria. For example, if the task was to hit 5 targets in 10 seconds and the user got 3, that's 60% success. Or if drawing, maybe measure the average deviation from the desired line. The eye data might

show, say, that the user took 2 seconds to find each target, which might be longer than an expert baseline.

7. **Difficulty Decision:** Based on the evaluation, a decision rule triggers:
8. If performance was above a high threshold (user did very well easily), increase difficulty for next task.
9. If performance was below a lower threshold (user is clearly struggling), decrease difficulty or provide help.
10. If performance is in an acceptable band (challenged but managing), keep difficulty the same for now. These thresholds can be dynamic; for instance, the system might aim to keep the user at roughly ~80% success rate (meaning they fail 20% of the time to ensure there's learning from errors[19]).
11. **Adjust Parameters:** Depending on the decision:
12. Increase difficulty: possibilities include introducing a **time limit**, adding background noise (e.g., irrelevant objects to distract, to train focus), requiring higher precision (smaller targets or narrower path to trace), or moving from partial inversion (if earlier, maybe only vertical flip) to full inversion.
13. Decrease difficulty: provide a **training wheel**. For example, enable a visual guide arrow for a moment showing which way to move, or enlarge the targets. If eye data showed they can't find targets, maybe highlight targets in a bright color or with a blinking outline to draw attention.
14. Maintain difficulty: no change, but perhaps the system still varies the tasks to avoid monotony (lateral adjustments that keep overall difficulty same).
15. **Provide Feedback:** Before or during the next task, the system might give the user feedback on how they did. Positive reinforcement ("Great job on that round!") if they improved, or encouragement ("Try focusing on the center of the target") if they struggled. This keeps the user informed and motivated.
16. **Next Task Starts:** The loop repeats with the adjusted settings.

This closed-loop approach is continuous during a session. Over multiple sessions, there may be a higher-level adaptation: the software can detect plateaus in performance and perhaps introduce **new task types** to challenge the user in a different way, preventing stagnation.

One significant aspect of adaptation is tied to **eye behavior**: If the user has adapted well, they will start to exhibit more "normal" eye-hand coordination even under inversion. Early on, subjects may have odd eye movements (e.g., looking in the wrong direction for objects, or needing to think longer before moving their eyes). As they improve, their brain's predictive model updates and they begin looking to where an object actually is in inverted view automatically. The system's eye-tracking analysis can confirm this improvement[1]. If after many sessions the user still shows extremely delayed or scattered gaze patterns, it might signal a need for a different training strategy or more fundamental intervention. This information is useful in a therapy context to personalize treatment.

Wearable Haptic Feedback Integration

Throughout the above descriptions, **haptic feedback** has been mentioned as an assistive component. We now detail the wearable haptic devices that can be used and their modes of operation:

The haptic component can take various forms: - **Vibration motors** attached to bands or clothing (similar to those in smartphones or game controllers). These can be placed on wrists, upper arms, shoulders, or other areas. - **Solenoid or piezo actuators** that can tap or apply pressure in a localized way (e.g., a small "thumper" that can tap the back of the hand). - **Inflatable bladders or pressure cuffs** that can squeeze gently (for example, a sleeve that can tighten slightly to indicate something). - **Electric stimulation pads** (though outside the typical "haptic", some rehab uses mild electrical stimulation; our system could theoretically interface with such a device to stimulate a muscle as feedback or encouragement for movement).

The system's control unit can drive these devices via a haptic driver module. The user might wear, say, a haptic glove (with small vibrators on each fingertip or joint) and a haptic vest (with larger vibrators on the torso). The glove could give fine feedback (like "buzz on index finger means you moved correctly, buzz on middle means error" or even directional cue by buzzing left vs right side of the hand to suggest moving that way). The vest could give more general cues (a chest vibration for success, shoulder vibrations to indicate direction of target relative to gaze, etc.).

During a tracing task under inversion, one strategy is to implement a **"virtual guide rail"**: If the user needs to trace along line A-B and they start drifting off line, haptic feedback can activate proportionally to the distance from the line. For example, if they drift upward (which in inverted view might mean their hand drifted downward physically), a vibration on the lower arm triggers, cueing them to correct upward (physically). Essentially it maps error direction to a tactile sensation[14]. Initially, this can significantly help keep them on track ("like bumpers in bowling"). Over time, the intensity of this error feedback can be reduced to encourage the user to rely on their own adaptation.

Haptics are also used as **positive reinforcement**: a distinct short buzz pattern (like two quick pulses) can mark task completion or hitting a target. Humans respond well to multi-sensory reward signals – combining a visual "hit" flash, a success sound, and a haptic pulse yields a more satisfying feedback than any single one alone, reinforcing the learning.

Care is taken to ensure haptic feedback itself does not confuse the user. For instance, if everything is inverted visually, one must decide whether to also invert any directional meaning in haptics. A straightforward method is to always map haptic cues to real-world directions (e.g., vibrate the left side if they need to move left in the real world, which in inverted view might correspond to some visual need). The user thus learns a consistent association: "When my left wrist buzzes, I should move my hand left". Over time, they might not need this because their brain adapts internally, but at the start it can act like "training wheels".

Notably, an experimental finding was that over-reliance on haptic cues can be detrimental if the goal is independent adaptation[15]. The system therefore might intelligently taper off haptic assistance as the user's performance improves (much like a teacher gradually gives less help). This can be part of the adaptive difficulty: the better the user gets, the less frequent or intense the error buzzes, so that by the end they are effectively performing under inversion with minimal aids, which indicates true adaptation.

Multiplayer and Competitive Feedback Loop (FIG. 5)

The multiplayer aspect of the system adds a social and motivational dimension to the training. In a multiplayer session (as conceptualized in FIG. 5), two or more users each use their respective setups (which could be identical types, e.g., both in VR, or even different – one in VR and one with physical setup, theoretically – though matching modalities is simpler for fairness). The systems connect via a network (local or internet) to a central game server that coordinates the session.

Competitive mode: Each user is given the same tasks to perform under inverted vision, and their performances are compared. For example, a time trial: "Who can hit 10 randomized targets first under inverted view?" The server monitors the hits each user makes. A scoreboard is updated in real-time – if User A hits a target, their count goes up and perhaps a lead indicator is shown to both users ("User A is in the lead!"). This immediate feedback creates a **feedback loop of competition**: User B sees they are behind and might intensify focus to catch up. Meanwhile, the system ensures both are challenged – it might even dynamically even the field by slightly increasing difficulty for the person in lead to keep the competition tight (one can optionally do that to prevent discouragement, akin to rubber-banding in racing games).

The competitive feedback can also involve direct interaction: in VR, two users could actually **see each other's avatars** and maybe even affect each other (like throwing virtual objects that become the other's targets, etc.). In a simpler implementation, it's just parallel play with score comparison.

Collaborative mode: Alternatively, a cooperative multiplayer mode can be employed. For instance, both users together try to achieve a high combined score or accomplish a shared task (like two people carrying a large inverted virtual object together, requiring coordination). This encourages communication and joint problem solving ("You move up – oh wait, up means down – okay you move physically up while I move down to get this thing aligned"). Such interactions can make therapy more enjoyable (imagine a therapist and patient playing together, or two patients training concurrently).

Therapeutic angle: Competition can spur **cognitive and motor engagement** that might not be achieved alone. In stroke rehab, for instance, studies have found that adding gaming elements increases patient engagement and repetitions. Our invention's multiplayer mode could be used in a clinic where several patients compete in a friendly tournament, thereby doing more exercises than they would in a solo session due to the excitement of competition.

Feedback Loop Specifics: The phrase "feedback loop" in FIG. 5 refers to how the system uses the performance of one user to influence the experience of another: - Direct: showing the opponent's progress (like ghost or splitting screen). - Indirect: if one user finishes early, perhaps they "win" that round and the system might prompt the other to continue practicing without pressure (or end the round with a summary). The winner's success might push the other to adapt strategies that the winner used if they can observe them. - The loop also includes adaptation in a multiplayer context: if one user is consistently dominating due to higher skill, the system could introduce a handicap (like adding a slight delay or extra inversion quirk for the advanced user) to balance and keep both engaged. This is analogous to adaptive difficulty but applied asymmetrically to maintain the competitive balance.

All user data from multiplayer sessions is also recorded. There could be a **leaderboard** system if used in a home context (comparing scores with others worldwide, adding motivation to practice daily to climb ranks). However, care is taken in clinical use to ensure competition remains positive and doesn't discourage those who might have impairments.

Therapeutic and Specialized Embodiments

Finally, to elaborate on the specific use-cases in **amblyopia, stroke rehab, and neurodevelopment**:

- **Amblyopia (Lazy Eye):** Traditional therapy for amblyopia involves forcing use of the weaker eye (e.g., patching the strong eye) to improve visual acuity and brain connectivity for the weak eye[20]. In our system, we can implement a mode where the **strong eye's view is inverted or otherwise degraded**, while the amblyopic eye sees normally or with less inversion. For example, in a VR headset, we could feed an upside-down image to the left eye (if that's the dominant eye) and a right-side-up image to the right eye (the amblyopic eye). The brain gets conflicting images and ideally will start relying on the right eye's correct orientation to accomplish tasks, thereby engaging it more. The tasks in this mode might be made easier initially (since the user effectively has to reconcile two different views – a very unusual condition). Over time, as the amblyopic eye gains strength (as measured maybe by improvements in performing tasks with that eye's input), the inversion to the other eye could be reduced. Another simpler approach is to just run the standard inverted training binocularly, but after some adaptation, have the user do some rounds with only the amblyopic eye (the other eye occluded), to see how well the eye alone can perform. The engaging nature of the games can help overcome the compliance problem seen in kids who might otherwise resist patching therapy. In essence, the system can be like a fun video game that incidentally exercises the weak eye.

- **Stroke Rehabilitation:** Many stroke survivors experience **hemiparesis** (weakness on one side) and need to retrain their brain to move limbs, as well as conditions like **hemispatial neglect** (not perceiving one side of space). Prism adaptation therapy has shown success in reducing neglect by shifting visual field[21]. Our inversion goggles similarly alter visual mapping and could be used to recalibrate spatial attention. For example, a patient with left neglect might wear inversion goggles that also perhaps include a slight left-right shift, forcing them to pay more attention to the left side (since it might appear on the right in their inverted view, etc.). The tasks can be tailored: reaching tasks with the impaired arm under inverted vision might encourage the brain to form new pathways for control because it's essentially learning "from scratch" in some sense, which can then transfer back to normal viewing (when goggles off, the hope is the improved general coordination remains). The system's data logs for stroke patients can provide quantitative outcomes (e.g., "Patient's reach error reduced from 20cm to 5cm over 2 weeks of training under inversion", or "speed of target acquisition with affected hand improved 50%"). This can complement clinical assessments. Additionally, the system can incorporate **functional tasks** important for daily living. For example, an AR version might guide a stroke patient through inverted practice of picking up objects or dressing (making it intentionally harder so that normal becomes easier by contrast).

- **Neurodevelopmental Disorders:** Children with conditions affecting motor skills (like Developmental Coordination Disorder, sometimes called dyspraxia) often benefit from performing motor exercises in a fun context. The inversion training adds a cognitive twist that could improve not just motor control but also problem-solving (figuring out the inversion) and **sensory integration**. The games can be designed with playful themes suitable for kids, and progress can be rewarded with in-game achievements to keep them engaged. For children with autism who may have sensory processing differences, the system allows exploration of an altered sensory world in a controlled way, potentially improving adaptability to sensory changes. However, caution is used to not overwhelm them; difficulty would be very gradually introduced. The adaptability of the system – e.g., adjusting visual contrast or complexity – can accommodate hypersensitivities or distractibility often found in these populations.

- **Healthy users and Skill enhancement:** Even for healthy individuals, using the system can sharpen their brain's adaptability. Some evidence in sports vision training suggests that practicing under difficult conditions (like strobe glasses that occlude vision intermittently) can improve overall performance once conditions return to normal[22]. Similarly, an athlete or pilot might use inverted training as a way to challenge their brain, possibly enhancing reflexes or the ability to handle disorienting stimuli (relevant for pilots or astronauts who may experience unusual orientation situations). Indeed, NASA has researched devices like inversion goggles for motion sickness training[3]. Our system could be used in that domain: train astronauts with inversion to speed up their visuo-motor adaptability, so that when they encounter zero-G disorientation or unusual frames of reference, their brains cope faster.

Across all these use cases, the **core architecture** of the system remains consistent: a means to invert vision, tasks to perform, and a loop of feedback and adjustment to facilitate learning. The modular design allows toggling various components (e.g., turning off haptics if not appropriate for a given user, or using only certain task types for a specific therapy). This flexibility is important for a product that might be used in both entertainment and medical contexts.

Software Architecture: To briefly note, the software running the system (on PC, console, or mobile device) can be structured into modules: - **Rendering Module:** handles displaying the environment (applies inversion transform to camera). - **Tracking Module:** collects input from motion sensors, controllers, eye tracker. - **Game Logic Module:** defines the sequence of tasks, game rules, scoring, timing. - **Adaptation Module:** implements the difficulty adjustment algorithm and communicates with game logic to modify parameters for the next round in real time. - **Feedback Module:** triggers audio/visual/haptic feedback events based on signals from game logic (e.g., on score events or errors). - **Data Logging Module:** records data to memory or cloud, and optionally provides post-session analytics (which could be shown in a UI or exported for research). - **Network Module:** (if multiplayer) handles synchronization of game state, sending minimal data like target positions or scores between peers or to a server, with latency considerations so that competition feels fair and real-time.

Security and privacy of data (especially in medical use) would be maintained by encrypting logs or anonymizing as needed.

Safety Considerations: Training with inverted vision can be intense. The system might include interspersed breaks and warnings (if it detects signs of excessive user discomfort, perhaps via erratic performance or a user pressing a pause button). Gradual exposure is important: initial sessions might be short (10-15 minutes) until the user builds tolerance, to avoid inducing strong dizziness or nausea[2]. The adaptive system could even detect from user behavior if a break is needed (e.g., if performance suddenly degrades significantly, maybe the person is fatigued or queasy). The system could then pause and advise a short rest.

In conclusion, the described inverted sensorimotor training system provides a versatile platform for exploring and harnessing the human brain's capacity to adapt to altered sensory conditions. By incorporating **multiple embodiments** (physical, VR, AR) and a rich set of features (adaptive algorithms, haptic feedback, gamification, and multi-user support), it significantly expands upon the basic concept of inversion goggles and turns it into a practical tool for learning and rehabilitation. The following claims set forth the novel aspects of the system and method in detail.