

# A Portable Vision-Based Head Tracking Exergame Solution for Neck Rehabilitation

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## Abstract

The current practice of neck rehabilitation is done through laser-pointing devices in a physical setup or Virtual Reality head-mounted devices, whereby the patient will control and navigate a laser beam to follow a specific pattern. These setups are cumbersome to the patient. We propose a portable computer vision-based marker-less head tracking exergame for neck rehabilitation. Our system retargets head postures to control a game object and considers neck mobility while incorporating movement modulation during posture overcompensation. This system would be tailored to the specific patient in the steps of automatic calibration and gameplay interaction. We used the head and body pose to calibrate the game scene dimensions, and the upper body joint angles to feedback the posture overcompensation in the form of gameplay variables augmentation. From our testing, it has shown that this is a viable exergame solution that could be adopted for neck exercise.

## 1. Introduction

Neck rehabilitation is one of the key areas in physiotherapy. Patients with whiplash associated disorder as well as non-traumatic chronic neck pain have been shown to exhibit improvement in motor control and proprioception of the cervical spine during neutral relocation test (Adlakha, Chhabra, and Shukla 2020). The current practice utilizes a laser pointer mounted on the head of the patient to train motor control and assess the proprioception of the neck in the neutral head position test. Through the laser pointer, the patient practices neck movement by control and tracing the laser beam to follow a standard pattern on a chart or diagram placed on the wall.

Although the laser-based approach seems to be a quick setup for a patient to control by the head with visual pointing as feedback for their rehabilitation exercise, there are several limitations: (1) the head-mounted laser pointer setup requires space and equipment which may limit its applicability and adoption by therapists and patients as a home exercise, (2) almost impossible to make the exercise interesting lead-

ing to lack of motivation from the patient resulting in lacklustre engagement of the patients, (3) the use of a physical chart for laser tracing does not cater for the mobility range of patients since the chart is fixed in dimension, and (4) the patient is not able to objectively measure their accuracy or degree of head movement with such laser-based setup.

Advancement in computer vision, artificial intelligent and sensor technologies have enabled motion tracking and 2D positional data analysis to be conducted using low-cost cameras and without the use of wearable sensors. This allows augmented reality related feedback to be incorporated into rehabilitation procedures via gamification and achieve significant improvement in patient engagement, adherence, and effectiveness of the regime.

In this paper, we present an exergame solution that utilizes computer vision-based marker-less head tracking with gamified augmented feedback for neck movement control exercises. This method would be able to address cumbersome physical charts and the hindrance from any form of head-mount device. In summary our contributions are:

- A head tracking motion retargeting method as an interactive mechanism to control a game object.
- This method could take into account the neck movement mobility while incorporating movement modulation during upper posture overcompensation via game-based augmented visual feedback.
- A gamified home-based neck rehabilitation platform that could be individualized and monitored by caregiver while incorporating automation.
- Objective measurement of neck movement and its accuracy.

## 2. State-of-the-art

The review by (Debnath et al. 2022) reported a taxonomy of work that utilizes computer vision-based approaches for

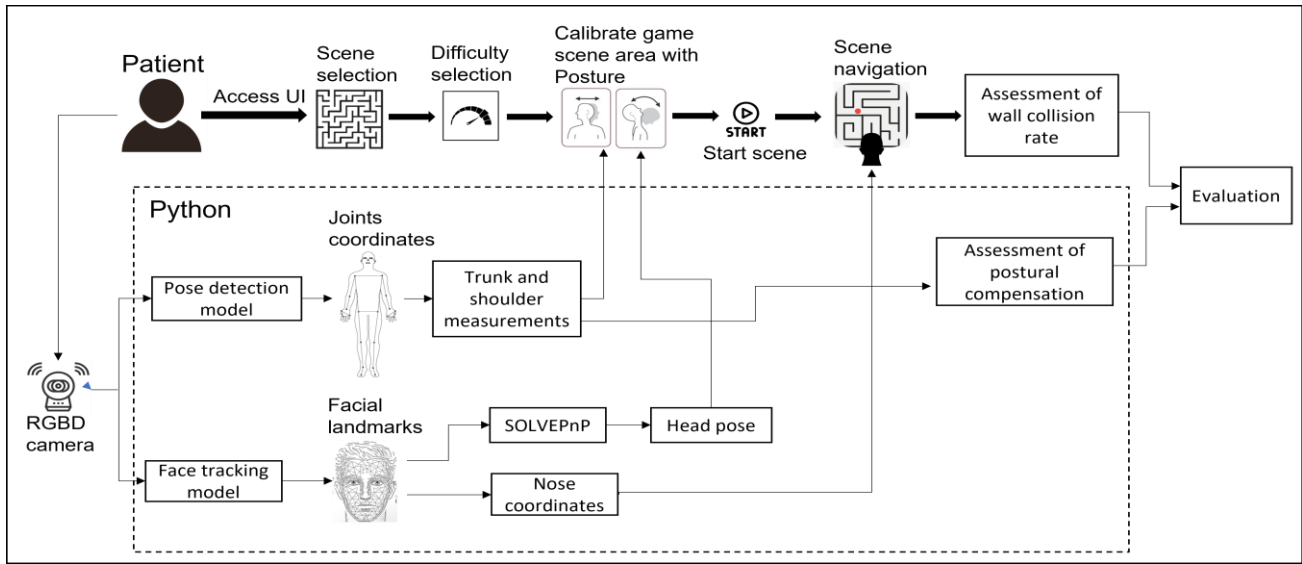


Figure 1: System overview of our computer vision-based head tracking solution for neck rehabilitation

physical rehabilitation and assessment from the computer vision perspective. Then the survey by (Zanatta et al. 2022) focused on reviewing usability of VR and robotics in the perspective of healthcare professionals and patients. Also, the review by (Liao et al. 2020) reported various computational methods for rehabilitation exercise. The evaluation of these exercises is categorized mainly into discrete movement score, rule-based and template-based approaches investigating the use of machine learning algorithms.

Numerous works had been proposed for rehabilitation to track the head/face via computer vision or graphics techniques. In the work of (Mihajlovia et al. 2017), they used VR-based head-mount devices that tracked head pose during rehab, while in (Xu et al. 2015) the authors evaluated the accuracy of the oculus rift virtual reality head-mounted display during cervical spine mobility measurement. Then in (Salinas-Bueno et al. 2021) the author presented a mobile application to perform neck exercise with 2D head tracking. Also, the work of (Abbaszadegan, Yaghoubu and MacKenzie 2019) investigated using of head tracking to control a virtual ball. Least but not least, other forms of motion sensor such as inertial measure unit (Gu et al. 2023) were reviewed, however these are wearables in which could impede and be hindrances to the user movement.

The interactivity of the human movement with the gameplay involves the process of *movement reproduction*. It was explained in a recent survey (Wang et al. 2023) that motion reproduction for interaction typically comprises the 3 typical components: (1) movement input, (2) movement representation, and (3) movement modulation. The movement input in this case is the head tracking component, hence the movement representation is the transformation of user

movement to visual appearance on the display device, which is typically controlling the movement of a virtual game object or avatar. Finally, the movement modulation is an intervention strategy that augment or modify the virtual movement representation aim to enhance the process of motor learning. The movement modulation could be categorized into (1) spatial-level, which operates on parameters like position and angle, and (2) temporal-level that act on movement cue such as walking speed (Lamontagne et al. 2007)

### 3. System Overview

Figure 1 shows an overview of our system. Our exergame would comprise the following components and steps:

1. Game scene and difficulty selection, and calibration of game scene with head and body pose
2. Head pose retargeting for game object navigation and interactive mechanics.
3. Assessment of upper body and head pose for postural overcompensation
4. Assessment of instances of collision of game object.
5. Evaluation of patient performance based on (4) and (5)

### 4. Methods

#### Game Scene and Difficulty Selection

Calibrating the dimensions of the game scene based on the extent to which their head is able to move in the yaw and pitch direction without overcompensation by upper body or head tilt. To customize for different patients, a calibrated game scene will provide a scenario that is personalized for

each patient based on their current condition. This contrasts with a physical maze or diagram with fixed dimensions that does not consider the neck range-of-motion (ROM) of the patient. This additional touch of personalization allows for a more engaging gameplay and provides a more accurate assessment of the patient’s progress for the therapist.

This exergame will also have in its database a series of mazes for the patient/ therapist to choose from based on the type of neck injury or rehab required by the patient. For example, a maze that requires more horizontal movement could be chosen if the therapist requires the patient to move his neck more in the yaw direction. As the patient progresses in his rehabilitation, the difficulty of the game could be modified by setting a shorter time limit to complete the maze or reducing the allowable error during game play.

### Retargeting Head Movement

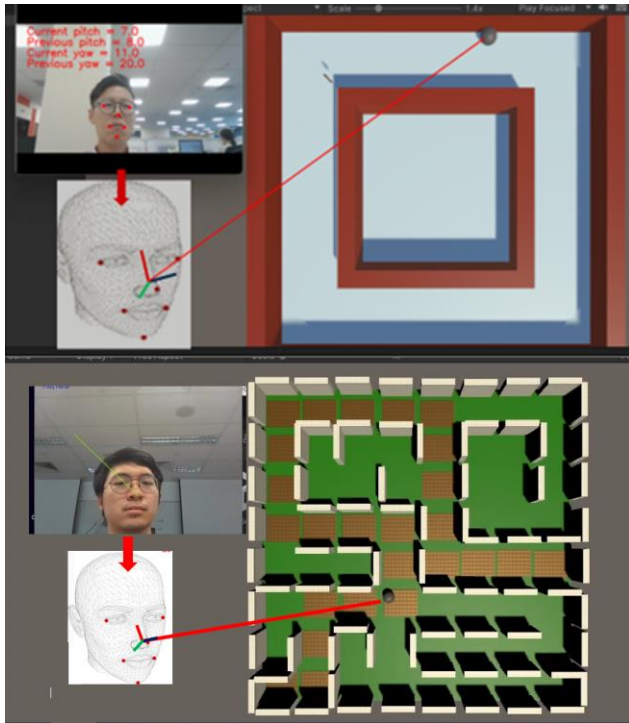


Figure 2: Retargeting of head pose to control a game object for maze navigation (different game complexity)

We will use the head pointing direction of the patient for navigating the game object in the game scene. The maximum head angles of the patient are calibrated to match the scale of the dimension of the game scene. During the navigation with the game scene, the game object will be moved to the position in the game scene corresponding to pitch and yaw of the head. The posture of the patient will be modulated to account for slight movement of the upper body.

As some slight movement of other parts of the upper body is inevitable while performing the neck rehabilitation exercise, we will account for the allowable ROM of the upper body before it constitutes overcompensation. To make it less sensitive to noise and false alarms, a hysteresis thresholding is applied. As shown in Figure 2, we retarget the head pose of the user to navigate in a maze by controlling the position of the ball game object (the ball in figure 2). The dimension of the maze is calibrated to the full ROM of the user neck.

Alternatively, we can use forward kinematics to move the game object in the scene via the change in head angle of the current sampled frame with respect to the last sampled frame, to move the game object by the same magnitude. The speed at which the game object is moved can be adjusted by the sampling rate. As such, we modulate the head movement of the patient such that the patient’s neck is moved in the required ROM at the required speed of the game level.

### Interactive Mechanics

In this system, we proposed two different kinds of interactive mechanics via (1) absolute ray forward casting and (2) retargeting of head pose to controlling WASD, with regards to gamification into controllable action for neck movement exercises. Correct execution of rehabilitative exercise is fed back to the patient in the form of level completion, accuracy of movement and augmented animations to motivate the patient to stay on to the routine. Calibration of the game scene will take place constantly with respect to their current condition while the difficulty levels are developed into the gameplay. Their progression can be incorporated into game score and be part of assessment criteria of the therapist. Our proposed method also allows the patient rehab process to be online and instructor-led, where instructor could monitor patients at the same time in a multiplayer setup.

### Upper Body Pose Computation



Figure 3: Key points for computing the assessment of upper postural overcompensation

The key points corresponding to the left shoulder joint, right shoulder joint, left hip joint and right hip joint are extracted

for upper body pose computation (Figure 3). These extracted key points are used for the computation of (1) shoulder length, (2) hip midpoint and (3) spine measurement. The shoulder length is computed by taking the Euclidean distance between the left and right shoulder joints of the patient. The hip midpoint is taken as the midpoint of the Euclidean distance between the left and right hip joint. The spine midpoint and the midpoint of the shoulder length.

### Head Pose Computation

The key points of the face are detected and extracted using BlazeFace face detector (Valentin et al. 2019), whereas the computation of the head pose is performed using the solvePnP (Terzakis and Lourakis 2020) function from the openCV library. This function treats the head pose estimation as a perspective-n-point (PnP) problem and uses (1) the coordinates of the face key points, (2) the predicted depth of each key point and (3) the camera intrinsic parameters to solve for it. Alternatively, an RGBD camera can also be used to acquire the 2D coordinates and depth of each key point. By solving the PnP problem, the camera's relative position and orientation to the head can be determined, giving us the head pose of the patient in every frame.

### Assessment of Posture Overcompensation

There is a need to modulate the movement of the patient to reduce compensatory movement from other parts of the body. We check for overcompensation of (1) unwanted head movement and (2) overcompensation of upper body movement during the calibration phase and gameplay.

We check the unwanted head movement by converting the estimated head pose estimation of the patient to Euler angle. As the patient is only permitted to move their head in the yaw and pitch axes, head movement in the roll axis will be considered as unnecessary. Thus, we will define a tolerance of 5° change per sampled frame for its roll-axis.

To check for overcompensation by upper body movement, we will use a modified version from the categories of compensatory motion for upper extremity rehabilitation exercises proposed by (Coias, Lee, and Bernardino 2022), which include (1) trunk forward/backward, (2) trunk rotation, (3) trunk tilt and (4) head roll. The patient will be prompted to redo his/her calibration or reduce the difficulty of the game if overcompensation of upper posture is detected. The upper body joints coordinates are detected and extracted by using the BlazePose pose detection model (Valentin et al. 2020).

## 5. Results and Conclusion

We have proposed a method to gamify neck rehabilitation by motion retargeting. This method begins by motion capture of the patient's head pose and retargets it to control the

movement of a game object that navigates in a game scene. Some of the The motion of the patient is also modulated to account for the patient's neck ROM with respect to the game scene dimension and upper body posture overcompensation through gameplay feedback. Lastly, the proposal of game scene complexity and game completion criteria are brought up to systematically track patients' progresses and enhanced engagement to the rehabilitative regime. Our preliminary testing has shown promising results which could be adopted in rehabilitation. Going forward, we aim to perform more rigorous user testing, precision validation and investigating different types of game scenarios and genres.

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### References

- Abbaszadegan, M.; Yaghoubu S.; and MacKenzie I. S. 2019. TrackMaze: A Comparison of Head-Tracking, Eye-Tracking, and Tilt as Input Methods for Mobile Games. *HCI 2018*, pp 393-405.
- Adlakha, S.; Chhabra, D.; Shukla, P. 2020. Effectiveness of Gamification for the Rehabilitation of Neurodegenerative Disorders. *Chaos Solitons Fractals*, vol 140.
- Coias, A. R.; Lee, M. H.; and Bernardino A. 2022. A Low-cost Virtual Coach for 2D Video-based Compensation of Upper Extremity Rehabilitation Exercise. *Journal of Neuro-Engineering and Rehabilitation 19*, Article 83.
- Debnath, B.; O'Brien M.; Yamaguichi, M.; and Behera, A. 2022. A Review of Computer Vision-based Approaches for Physical Rehabilitation and Assessment. *Multimedia System*, vol 28, pp 209-239.
- Gu, C.; Lin, W.; He, X.; Lei, Z.; and Zhang, M. 2023. IMU-based Motion Capture System for Rehabilitation Applications: A Systematic Review. *Biomimetic Intelligence and Robotics*.
- Lamontagne, A.; Fung, J.; McFadyen, B. J.; and Faubert, J. 2007. Modulation of Walking Speed by Changing Optic Flow in Persons with Stroke," *Journal of Neuro-Engineering and Rehabilitation*, vol. 4(1).
- Liao, Y.; Vakanski A.; Xian, M.; Paul, D.; and Becker, R. 2020. A Review of Computational Approaches for Evaluation of Rehabilitation Exercises. *Computers in Biology and Medicine*, vol 119.
- Mihajlovic, Z.; Popovic, S.; Brkic, K.; and Cosic K. 2017. A System for Head-Neck Rehabilitation Exercises based on Serious Gaming and Virtual Reality. *Multimedia Tools and Applications*, vol 77.

Salinas-Bueno, I.; Roig-Maimó, M. F.; Martínez-Bueso, P.; San-Sebastián-Fernández, K.; Varona, J.; and Mas-Sansó, R. 2021. Camera-based Monitoring of Neck Movements for Cervical Rehabilitation Mobile Applications. *Sensors*, 21(6):2237.

Shum, L. C.; B. A. Valdes, N. J. Hodges, and H. M. Van der Loos. 2019. Error Augmentation in Immersive Virtual Reality for Bimanual Upper-limb Rehabilitation in Individuals with and without Hemiplegic Cerebral Palsy. *IEEE Trans. Neural Syst. Rehabilitation Eng*, vol 28(2).

Terzakis, G.; Lourakis, M. 2020. A Consistently Fast and Globally Optimal Solution to the Perspective-n-Point Problem. In *Proc ECCV*.

Valentin, B.; Ivan, G.; Karthik, R.; Tyler, Z.; Fan, Z.; Matthias, G.; 2022. BlazePose: On-device Real-time Body Pose tracking. In *CVPR 2022*.

Valentin, B.; Yury, K.; Andrey, V.; Karthik, R.; Matthias, G. 2019. BlazeFace: Sub-millisecond Neural Face Detection on Mobile GPUs. In *CVPR 2019*.

Wang, L.; Liang H-N.; Yang, R.; and Han, J. 2023. Survey of Movement Reproduction in Immersive Virtual Rehabilitation. *IEEE Trans Vis Comput Graph*, vol 29(4).

Xu, X.; Karen, B, C.; Jia-Hua, L.; Robert, G, R. 2015. The Accuracy of the Oculus Rift Virtual Reality Head-mounted Display during Cervical Spine Mobility Measurement. *J Biomech*, 16(4).

Zanatta, F.; Anna, G.; Pierobon, A.; D’Addario, M.; Steca, P.;2022. A Systematic Review on the Usability of Robotic and Virtual Reality Devices in Neuromotor Rehabilitation Patients and Healthcare Professionals’ Perspective. *BMC Health Services Research*, 22, Article number: 523.