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Integrating vision-based head movement detection into a serious game towards game-based neck pain treatment

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Abstract

Serious games are a type of virtual game whose objective goes beyond entertainment, an application is the rehabilitation of the user, increasing their motivation and therefore improving the effectiveness of therapies. The aim of this project is *to develop a serious game for patients with different degrees of cervicalgia, cervical osteoarthritis, or any condition that affects the mobility of the cervicals*. To do this, the classic Pac-Man video game has been used together with a vision system capable of detecting the face and its orientation. By combining these modules, Pac-Man's movement on the map is controlled according to the orientation of the patient's face. A major advantage of this type of therapy compared to conventional therapies is the ability to objectively assess the patient. The video game can record multiple quantitative variables that indicate the patient's progress. However, a disadvantage could be the fatigue or frustration that may arise if the patient fails to play the game adequately. This drawback can be solved by adapting the level of the game to the patient's capabilities.

Keywords: Computer vision, Rehabilitation, Serious games, Face recognition

Integración de detección del movimiento de cabeza en un juego serio para el tratamiento del dolor de cuello

Resumen

Los juegos serios, conocidos en inglés como *Serious Games*, son un tipo de videojuego cuyo objetivo va más allá del entretenimiento. Una aplicación habitual de esta tecnología es la rehabilitación funcional fomentando la motivación del paciente y mejorando por tanto la efectividad de las terapias. El objetivo de este proyecto es *desarrollar un juego serio para pacientes con diferentes grados de cervicalgia, artrosis cervical, o cualquier condición que afecte la movilidad de las cervicales*. Para ello, se ha utilizado el clásico videojuego arcade del Pac-Man junto con un sistema de visión capaz de detectar el rostro y su orientación. Al combinar estos módulos, el desplazamiento de Pac-Man en el mapa se controla según la orientación del rostro del paciente. Una gran ventaja de este tipo de terapia en comparación con las terapias convencionales es la capacidad de evaluar objetivamente al paciente. El videojuego puede registrar múltiples variables cuantitativas que indican el progreso del paciente. Sin embargo, una desventaja podría ser la fatiga o la frustración que puede surgir si el paciente no logra jugar adecuadamente. Este inconveniente se puede resolver adaptando el nivel del juego a las capacidades del paciente.

Palabras clave: Vision por computador, Rehabilitación, Juegos serios, Reconocimiento facial

1. Introduction

Neck pain is one of the most common musculoskeletal disorders, having an age-standardized prevalence rate of 27.0 per 1000 population in 2019 (Kazeminasab et al., 2022). Individuals suffering of cervical pain may have difficulties with many activities, such as driving a car, turning the head and working on a computer. They may also have a reduced ability to participate in work, social and sporting endeavors, which in turn

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can further increase the burden associated with neck pain (Wu et al., 2024).

Common treatments to relieve the cervical pain problems include taking showers with water at the highest pressure and tolerable temperature on the neck and shoulder region for 10-15 minutes followed by flexo-extension and lateral movements of the neck for another 10-15 minutes. Some studies support the efficacy of exercises aimed at different aspects of sensori-motor function, such as training aimed at improving perception and muscle coordination, to promote functional gains that reduce cervical pain (Röijezon et al., 2008).

In recent decades, serious games and gaming technology has been accepted as a feasible method to complement the traditional clinical practice. Serious games are a type of virtual game designed for purposes beyond entertainment, such as education, vocational training, health and rehabilitation. These games use mechanics and dynamics to engage users in activities that promote learning, skill acquisition or improvement of health conditions. By combining entertainment with practical objectives, serious games can increase user motivation and engagement, providing a safe, interactive environment where tangible and measurable results can be achieved. Serious games are socially accepted for a variety of reasons, including their low level of intrusiveness, the safety they offer during therapy, their attractiveness compared to conventional therapies and the positive results obtained (Tolentino et al., 2011).

On this context, several tools based on gaming technology has been developed for measuring and treating the symptoms of diseases such as multiple sclerosis (Cuesta-Gómez et al., 2020), stroke (Aguilera-Rubio et al., 2022), Parkinson's disease (Oña et al., 2020), among others. These type of applications have shown positive results in treatment effectiveness, satisfaction, adherence and user's experience. However, few work have been conducted in the use of gaming-based treatments to reduce problems related with neck pain.

1.1. Related work

In the domain of assistive technologies, various systems have been developed to enhance the quality of life for individuals with severe disabilities. One such system is EViacam (Enable Viacam), a software application that allows users to control the mouse pointer on a computer screen using head movements captured via a webcam. EViacam has been widely recognized for its ease of use and accessibility, making it a popular choice for people with motor impairments.

Other significant works in this field include the development of the "Camera Mouse" system, which provides computer access for individuals with severe disabilities by tracking body features such as the tip of the user's nose or finger (Betke et al., 2002). This system translates these movements into mouse pointer actions, enabling users to interact with computers more effectively, demonstrating the effectiveness of the camera mouse in improving the communication ability of users with severe cerebral palsy and traumatic brain injury.

Both EViacam and Camera Mouse can be used for serious games by detecting head movements to control game environments. However, there are several limitations that make these systems less effective.

For EViacam, while it allows control of the mouse pointer through head movements, its limitations include a dependency on good lighting conditions and high webcam quality for accurate tracking. This can lead to inconsistent performance in different environments. Additionally, EViacam is primarily designed for basic cursor control rather than complex gaming interactions, which may limit its responsiveness and precision in fast-paced or high-interaction games.

Similarly, Camera Mouse can also detect head movements to control a mouse pointer and be used in some games. However, its performance is significantly affected by the quality of the webcam and the lighting conditions. The system tends to lose accuracy with smaller targets and has difficulty maintaining consistent tracking if there are changes in lighting or if the user moves out of the camera's view. Additionally, Camera Mouse is not designed for fine-grained control required in many serious games, potentially resulting in a less immersive and less responsive gaming experience.

Acute and chronic neck pain are common medical conditions, and the treatment typically includes physical therapy involving daily exercises. However, insufficient motivation of patients to adhere to the prescribed exercise regimen may delay their recovery. On this context, the use of serious games can improve the user's motivation to perform neck exercises.

On one side, an immersive VR-based system that measures the user's neck movements through static and dynamic kinematic tests is presented in the Mihajlovic et al. (2018) study. The neck measurements are sent to a serious game to promote specific movements. Other example is the Luc et al. (2023) study, that explores the experience of people with chronic non-specific neck pain (CNSNP) who used immersive VR serious games at home, targeting cervical range of motion, speed, and control of movement. The results of VR-based training show that the user's engagement is increased and the potential of immersive VR in home-based rehabilitation. However, the use of an immersive environment may include additional load to the neck motion due to the VR headset weight.

On the other side, a multi-modal input system for 2D serious games is proposed by Schönauer et al. (2011), integrating a Microsoft Kinect device to detect body motion and control the videogame actions focusing on the motor rehabilitation of chronic pain patients. The implemented videogames focused on identifying walking movements, hand positions, and neck rotations. Results shown positive trend of decreasing pain intensity score in walking, but there is no further testing in neck functioning. Similarly, Gonçalves et al. (2023) developed serious games to assist health professionals in the physiotherapy of patients with spinal pain for clinical and home applications. The videogame actions are controlled via body movements which are detect through a vision system based on OpenPose.

Finally, Beltran-Alacreu et al. (2022) develop and assess the suitability of a serious game for performing task-oriented cervical exercises in patients with neck pain. The gameplay focused on controlling a virtual airplane to reach targets using head motions. This system was tested with an older adult cohort, showing that the game-based method is safe and offer also positive results in satisfaction and acceptance.

On the account of the above, we propose a game-based system to promote the engagement of patients to perform neck exercises in a friendly environment. In this paper, the development of the game environment and the neck movement tracking are presented. The reminder of this paper is as follows: Section 2 presents the system components and its architecture. Section 3 describes the implementation details of the vision module to track head motions and the virtual environment features. Finally, the system functionalities and conclusions are discussed in Section 4.

2. System Architecture

For the development of this application, we have chose an arcade videogame denoted as Pac-Man. The gameplay of Pac-Man is simple and intuitive, and only requires few commands to control the player's motion. In this case, the goal is to control the player's motion around the labyrinth using head movements. Figure 1 depicts the system architecture and presents the three main components: the vision-based module to track the head motion, the communication interface, and the videogame.

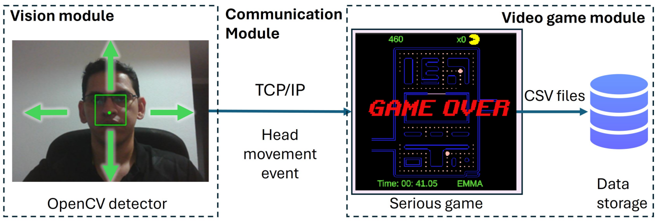


Figure 1: System Architecture.

Vision Module:

The vision module is the fundamental component of our architecture, responsible for capturing and processing the patient's head movements in real time. Head detection is performed by computer vision techniques using Python. This module uses image processing algorithms to identify and track the position and orientation of the patient's head.

To determine the vertical or horizontal movement of the head, algorithms are applied to track a key point which is the nose, bounded by a quadrant, necessary to calculate the direction of the movement, thus allowing to discern between vertical (up or down) and horizontal (left or right) movements.

The vision module provides accurate information about head movements, which is crucial for patient interaction with the game and the generation of relevant data for further analysis.

Communication Module

Once the vision module has detected the head movement, the next step is to transmit this information to the game environment implemented in Unity. This process is carried out through a network protocol using sockets. Python acts as the data sender, while Unity is responsible for receiving and processing this data to update the character's movement in the Pac-Man game. Efficient communication between these two systems is crucial to ensure a smooth and synchronized gaming experience with the detected movements.

Serious Game module

The Serious Game module constitutes the interactive part of our architecture, implemented in Unity. Using the head movement data provided by the vision module, this component controls the behavior of the Pac-Man game.

The Pac-Man game adapts dynamically according to the detected movements, allowing the patient to control the direction of the main character using only head movements. For example, if a movement to the right is detected, the Pac-Man character will move in that direction within the virtual maze. This creates an immersive and participatory gaming experience, which in turn facilitates rehabilitation and monitoring of the patient's progress.

3. System Development

In the gaming world, customization is key to delivering unique and engaging patient experiences. With Serious Games, a versatile and powerful platform, you can take the classic Pac-Man game experience to the next level by adding elements that increase the excitement and interactivity of the game.

3.1. Serious Game: Pac-Man Game

The first step in the design process of our Pac-Man game in Unity is setting up the project and the main scene. We start by creating a new 2D project in Unity, using version 2022.3.13f1. Once the project is created, we rename the main scene to "Pac-Man" for organizational purposes. Next, we adjust the camera settings in the Inspector, setting the background color to black, the size to 18, and the Y position to -1. This ensures that the camera is correctly configured for the game's display.

Next, we configure the collision matrix. In the project settings, under *Physics 2D*, we set up the *Layer Collision Matrix* to define how different objects in the game interact. We create a GameObject and, from the Inspector, add five new layers: *Pac-Man*, *Ghost*, *Pellet*, *Obstacle*, and *Node*. This allows us to manage collisions precisely and effectively.

For the game sprites, we create a new folder called "Sprites" and copy all the necessary sprites into it. We adjust the resolution of these sprites in the Inspector, setting the *Pixels Per Unit* to 8, *Filter Mode* to Point (no filter), *Max Size* to 32, and *Compression* to None. Specifically, for the sprites of *Walls*, *Pellets*, and *Node*, we set *Pixels Per Unit* to 24 to ensure correct display in the game.

Creating the Pac-Man maze is done using Tilemaps. In the project hierarchy, we add a new rectangular Tilemap and rename it *Walls*, assigning it to the *Obstacle* layer. This allows us to draw the maze walls. Using the scene view, we open the *Tile Palette*, create a new folder called "Tiles", and set up a new tile palette named *Tile_Palette*. We select all the wall sprites and drag them into this palette, enabling us to design the maze accurately. It is important to leave a gap between the walls as a path for Pac-Man to move through.

For the pellets, we create a new Tilemap called *Pellets* and assign it to the appropriate layer. We create a Prefab from a GameObject named *Pellet*, to which we add a *Sprite Renderer* and select the *Pellet_Small* sprite. We add a *Box Collider 2D*, marking *isTrigger* and adjusting its size to 0.25 in both dimensions. We save this Prefab in the *Prefabs* folder. We repeat this process for the *PowerPellets*, adjusting the sprite and collider size to 1. Finally, we create Rule Tiles for these prefabs, configuring them in the *Tile_Palette* and ensuring the correct tile is active when designing paths with pellets and PowerPellets.

The creation of nodes is done through a new Tilemap called *Nodes*, assigned to the corresponding layer. We create an empty GameObject, name it *Node*, and assign it to the *Node* layer. We add a *Box Collider 2D* with a size adjusted to 0.5 in both dimensions and save this object as a Prefab. We set up a Rule Tile for this Prefab, selecting the appropriate sprite and ensuring the nodes are correctly placed in the maze.

Finally, to manage the game logic, we create an empty GameObject named *GameManager* and reset its transformations. We create a folder called *Scripts*, where we add a new script named *GameManager* and attach it to the corresponding GameObject. This script will manage the game flow, including handling Pac-Man's movements and the ghosts, as well as interactions with the pellets and other maze elements.

With these steps, we have set up a robust and modular game environment, allowing us to develop and adjust each part of the Pac-Man game in Unity easily. This structured approach ensures that the maze design and game interactions are precise and efficient, providing a solid foundation for programming game logic and implementing additional features.

The game methodology aims to implement different levels of difficulty, with the intention that rehabilitation goes in parallel to the patient's progress, for this we have the following features.

- **Main Menu:** The user can enter his or her name and select the desired game mode, which allows personalisation of the therapy.

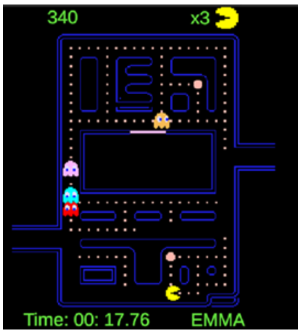
- **Therapy levels:** Different mazes have been designed depending on the desired level to be performed by the patient, a classic one for the easy game mode and a more complex maze for the difficult mode (Figure **??**). These maps have been created using the tool provided by Unity. Additional has also been modified for each level, the speed of character movement. This could be scaled to multiple levels by modifying other variables that interact with the game environment.

- **Time Management:** It records the time it takes the patient to complete a map, providing quantitative data for subsequent evaluation of the session.

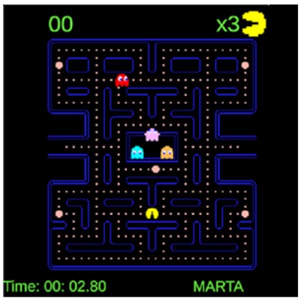
- **Game functionalities:** Creation of lives, scoring, passages, different types of ghosts and the possibility of eating them.

- **Linking Gaming with Vision:** A vision algorithm capable of detecting the patient's face and transmitting its movement to the Pac-Man's displacement was implemented.

- **Session data automatic record:** Quantitative data collected during the session are automatically saved in a .cvs file to allow further evaluation and follow-up of the patient's rehabilitation status.



(a) Map Easy Mode



(b) Map Hard Mode

Figure 2: Level Maps

The Serious Games module has a component in Unity to receive motion data from a main entity. This component, called "HeadMovementReceiver", is responsible for establishing a socket connection with a local server, receiving movement data through this connection, and applying it to an object in the game. It uses the Unity Engine, System.Net.Sockets, and System.Text libraries to handle socket communication and process the received data.

And another component to receive motion data from a main entity and apply it to a Pac-Man object in a game. The component, called "Pac-Man", uses the Unity Engine and System libraries to handle the character's movement in response to instructions received. Functions are set to initialize the component, update its state at each frame, reset its state, and handle the death sequence.

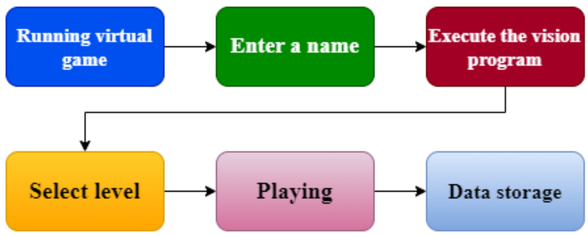


Figure 3: Flowchart of the serious game

Therefore, the procedure to start a game is shown in Figure 3. This model is simple, allowing an easy implementation so that both the clinician and the patient can follow the indications without the need of the developer. In addition, this simplicity allows the patient to perform the therapies from home in an entertaining way, providing the clinician with quantitative data on the follow-up of the rehabilitation exercises. This reduces waiting lists and improves the quality of the intervention.

3.2. Vision algorithm

The vision algorithm is responsible for determining the orientation of the user's face. It detects the face and locates the minutia corresponding to the nose coordinate. In addition, it frames a rectangle in the center of the image. Depending on the relative position of the minutia of the face with respect to the rectangle, the algorithm can detect the pose of the user.

This algorithm has been developed in Python 3.12.3, implementing the OpenCV 4.9 and Mediapipe 0.10.14 libraries. Using Mediapipe in conjunction with OpenCV enables accurate and fast detection of key facial points, significantly improving the algorithm's real-time performance. Mediapipe offers an optimized implementation for facial feature identification, facilitating the exact location of the minutiae corresponding to the nose. This technology combination ensures that the algorithm can operate efficiently in a variety of environments and lighting conditions, guaranteeing a consistent and reliable user experience.

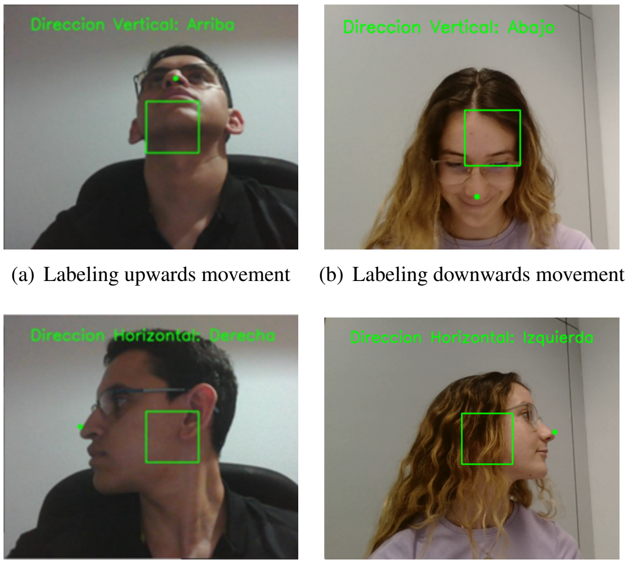
First, communication with the video game is established to transmit the obtained commands. Next, the video is captured from the front camera of the laptop. If the program is still running, the different frames are analyzed to detect the different faces and obtain their respective coordinates. From these coordinates and their position with respect to a box centered in the image, the orientations that the user wishes to achieve are obtained. These orientations are sent to the video game to achieve the desired displacement.

Algorithm 1 Head Movement Detection

```
Start the vision module (python)
Configure the face detection library and the server socket
while the program is open do
    Capture a frame from the camera
    Convert the frame to RGB
    Process the frame for facial landmarks
    if at least one face is detected then
        for each detected face do
            Get the position of the nose
            Determine the direction of facial movement
            Draw a reference square in the center of the screen
            Show the direction of movement on the frame
            Send the movement data over the socket
        end for
    end if
    Show the processed frame in a window
    if the 'q' key is pressed then
        Exit the loop
    end if
end while
Release camera resources and close all windows
```

Pseudocode 1 outlines the general structure of the program, including face detection, calculating the direction of facial movement, displaying the direction of movement in the frame, and sending the movement data over the network via sockets. The code for this system is available in `https://github.com/YEPEZ25/UC3M-Neck-rehabilitation-using-Serius-Game`.

To contrast and check the algorithm performance, the following graphical results are shown in Figure 4, we verify the obtaining of the characteristic coordinate of the face belonging to the nose, and the square that is going to work as our reference system.



(a) Labeling upwards movement (b) Labeling downwards movement

(c) Labeling right movement (d) Labeling left movement

Figure 4: Validation of the labeling.

The results obtained from the rehabilitation system based on the Pac-Man game show an accuracy of more than 95% in the detection of the patient's head movements, provided the following conditions are met:

- **Patient Positioning and Centring:** The patient must be positioned within and centred in the frame set by the vision system. This position is crucial for the motion detection algorithm to function correctly.
- **Range of Motion:** The patient's movements must be able to exceed the range defined by the system, allowing clear and accurate detection of vertical and horizontal head movements.
- **Adequate illumination:** Good illumination is essential for the camera to capture video with sufficient quality, which facilitates image processing and motion detection.

These results have been obtained through tests on five completely healthy people without cervical injuries. The system has proven to be effective in detecting and tracking head movements, allowing precise control of the character in the game and therefore an effective tool for the rehabilitation of patients with cervical problems.

4. Discussions and Conclusions

In this paper, a vision-aided videogame-based system is presented, aiming to improve the treatments to relief neck pain. The integration of face recognition module into the videogame module is completed and the whole system presents a good performance in healthy users as mentioned above. However, there is room for improvements.

The vision system may be effective for detecting large and obvious movements of the nose relative to the reference frame, it may not be suitable for capturing very small movements due to limitations in the sensitivity and accuracy of the motion detection system. The incorporation of robotic cervical collars into the rehabilitation of patients with neck problems can significantly improve treatment efficacy through advanced sensing and active motion assistance Arockia Doss et al. (2023). These devices, equipped with sensors such as accelerometers and gyroscopes, provide real-time feedback on neck movements, allowing dynamic and personalised adjustments to rehabilitation programmes. In addition, actuators built into the collars can provide variable resistance or assistance during therapeutic exercises, facilitating complex movements and reducing muscle tension Lingampally and Arockia Doss (2021). The integration of these devices with vision systems that monitor and analyse the patient's movements further optimises the rehabilitation process, enabling patients to regain full neck mobility and improve their quality of life.

Functional rehabilitation of the neck is crucial to improve mobility and function in patients with chronic pain. It is recommended to include vertical (flexion and extension) and horizontal (rotation) movements to strengthen the deep cervical muscles and improve stability during daily activities. In addition, exercises such as combined flexion and rotation, seated cervical protraction, standing cervical retraction, neck flexion touching the head, and combined extension and rotation are beneficial for comprehensive recovery. (Worsfold, 2020))

Implementing these exercises with OpenCV will require algorithms to detect and track key facial points, calculate angles and distances to control movements, and integrate detection of other body points for more complex movements.

A serious game has been developed to aid in the rehabilitation of cervical spine mobility problems. This game, based on Pac-Man, was created in Unity and uses Python with OpenCV for a vision algorithm that records the patient's movements. Work has been done on extending the game modes to suit the individual needs of each patient, as well as identifying other useful metrics to assess their progress.

Preclinical trials are suggested for future plans to confirm the effectiveness of the game compared to conventional therapies.

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