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MediMoov, a Physio-Gaming Platform with Real-Time Interaction through Limbs Movements and Affordable Multi Modal Sensors

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This article introduces the MediMoov platform, a software designed for motor rehabilitation, which leverages motion-based interaction methods to combine video gaming with physical therapy exercises (physio-gaming). It's widely used in various healthcare environments, including rehabilitation centers and retirement homes. Users support its effectiveness, ease of use, simple setup, and diverse exercise options. Despite its success, MediMoov faces challenges, notably its reliance on the Microsoft Kinect v2 sensor. User feedback indicates a need to expand movement range for finer motor skills and enhance motion capture for disabled users. Clinicians desire a motion estimation tool offering biomechanically pertinent data. To address these issues, the article suggests upgrading MediMoov with advanced motion estimation, tracking, and gesture recognition technologies compatible with different sensors, including RGB cameras. These enhancements aim to make the platform more inclusive and effective in rehabilitation through physio-gaming, enlarging its utility and improving user experience for a diverse range of needs.

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1 INTRODUCTION

A significant portion of older adults face physical disabilities, especially issues related to motor and cognitive functions [6]. Games can be a valuable tool in environments catering to the elderly, as they offer engaging activities that can stimulate motor and cognitive function and support overall well-being [10, 20, 24]. In the context of senior care, utilizing games as an activity can provide older adults with the opportunity to maintain and enhance various skills, including cognitive and motor abilities [10, 20, 24]. For the elderly, computer games are an appealing form of entertainment and mental exercise. However, for those with motor limitations, traditional input devices may not be adapted, necessitating the use of assistive technology for an inclusive participation [27]. For these individuals, motion-based games (physio-gaming) emerge as an effective solution [10, 20, 24], enabling them to interact with computer systems or games in a way that accommodates their physical capabilities.

Recent advancements have introduced a novel methodology for producing personalized gestural interactions [3]. The methodology allows to construct interactive systems that are adaptive to an individual's residual functional movements [2]. In an initial investigation, this method was applied to design gesture-based games, aiming to enhance communication abilities in individuals with disabilities [2]. The outcomes of this study are encouraging, suggesting potential applications of this methodology in the development of new interactive games.

Below methodological considerations, motion-based interaction with physio-games requires real-time motion estimation, recognition, and tracking, which is a challenging task due to its high interdisciplinary nature and wide range

of applications such as rehabilitation monitoring [1, 15, 16], physio-games interaction [10, 20, 24], and human-robot interaction [17, 18].

Interacting with a machine through motion requires the real-time determination of body keypoints Cartesian data such as 3D positions, angular velocities, and/or linear accelerations. These Cartesian data can then be used for real-time limbs motion estimation, or gesture recognition. Stereophotogrammetric systems provide gold standard Cartesian data which can be used for human motion assessment [8]. However, their cost and non-portability hinder their wide use for motion-based human-machine interaction. Recently, affordable and portable motion capture systems based on markerless visual data using RGB [14, 25, 26] and RGB-D [5, 24] cameras, wearable visual or inertial sensors [1, 13, 16, 19, 21, 23], and multi-modal sensor fusion approaches coupling visual and inertial data [1, 7, 16], were proposed. Custom algorithmic solutions, specific to each modality and use case, were developed to estimate the limbs motion [1, 5, 14, 16, 19] and classify gestures [7, 13, 22, 23].

Real-time motion estimation involves the tracking of raw Cartesian data [14, 24] and the estimation of joint angles. This estimation is achieved by applying Inverse Kinematics (IK) algorithms to raw Cartesian data. The state-of-the-art algorithm for real-time human motion tracking through multi-modal Cartesian measurements is the extended Kalman filter [15, 16] which can estimate joint angles, velocities and accelerations, given a description of the limbs mechanical model which is parameterised by segments lengths and sensors locations with respect to the limbs [1, 15, 16]. Such an approach removes the measurements outliers intrinsic to affordable sensing modalities, while estimating smooth joint angles and their corresponding Cartesian measurements, which can increase the the quality of interaction with continuous motions

Gesture recognition consists in movement classification either from Cartesian data [22, 24] or joint angles [23], allowing an interaction based on predefined gestures. State-of-the-art approaches consist in using deep learning approaches to train a neural network classifying gestures [23].

Ideally, a physio-game should allow interactions through both continuous motions and specific gestures, from any Cartesian measurement modality. Furthermore, leveraging joint angles for gesture classification allows to have a classifier that is flexible to Cartesian measurement modalities, and increases the accuracy of gesture detection, as joint angles are invariant with respect to the subject's segment lengths and morphological particularities, contrary to Cartesian data [23].

The proposed approaches focused either on estimating human motion for rehabilitation applications [1, 16], or for gesture recognition from joint angles in an industrial context [23]. The literature does not propose a framework that leverages state-of-the-art real-time motion estimation and gesture recognition algorithms, adapted to physio-games interaction through any body part, accessible to disabled persons, and flexible to multiple affordable Cartesian sensing modalities.

In this context, NaturalPad, a company developing physio-games, has already commercialised the MediMoov platform [24] that allows a real-time interaction with video-games through motion tracking and gestures recognition based on a Microsoft Kinect v2 RGB-D sensor. The MediMoov gaming platform, designed for the elderly and patients with reduced mobility, has been used for 8 years by more than 100 residential care homes. This extensive usage over the years has provided us with a significant amount of user feedback. We aim to leverage this feedback, integrating it with state-of-the-art human-computer interaction methodologies [2, 3], motion tracking [1, 5, 12, 16] and gesture recognition [7, 12, 22, 23] algorithms, into a new version of the platform. This new version will facilitate real-time interaction with video games through multiple measurement modalities, ranging from single RGB cameras to RGB-D cameras and wearable visual/inertial sensors. Depending on the available sensing modalities, the platform will allow to interact

with physio-games and/or estimate clinically relevant data in terms of biomechanical description of the participant's movement. The initial milestone of the update will involve developing a method that utilizes state-of-the-art motion tracking and gesture recognition algorithms, for markerless interaction with video games from a single RGB camera. Section 2 will present the MediMoov gaming platform, in its current state, developed for motion-based physio-games. Section 3 discusses users feedback gathered during last few years. Section 4 provides possible methodological and algorithmic improvements through state-of-the-art algorithms. Section 4.4 will introduce a preliminary framework architecture, and Section 5 will provide a conclusion.

2 MEDIMOOV GAMING PLATFORM

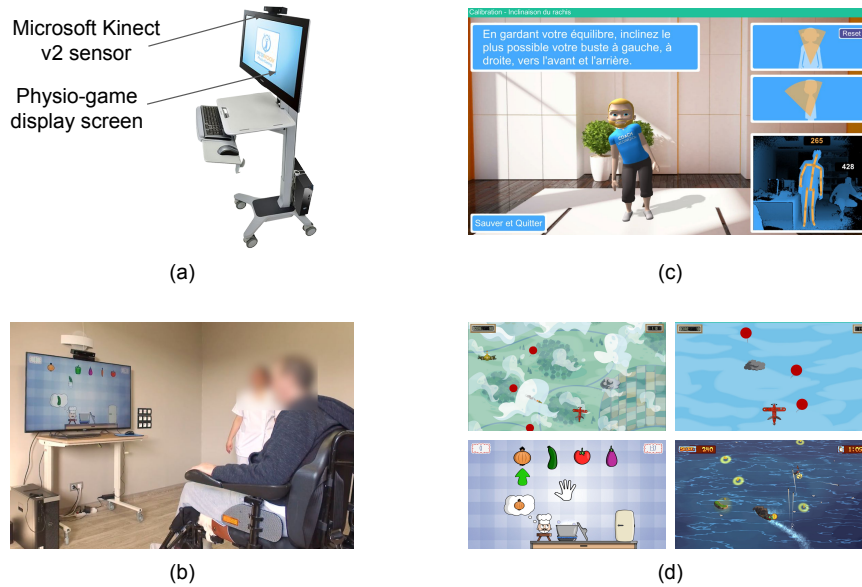


Fig. 1. Overview of the current version of MediMoov platform. (a) The MediMoov device composed by a Microsoft Kinect v2 sensor and a physio-game display screen. (b) A typical setup allowing a person in wheelchair playing physio-games through adapted motions. (c) The physio-game interface manager that adapts the interaction to the user's motor capabilities. (d) Snapshots of various physio-games.

MediMoov is a gaming platform for motor rehabilitation that combines video games with physical therapy exercises, adapted to elderly users. This platform integrates a variety of single-player video games and movements, designed to meet different therapeutic requirements [24]. In the current version, the use of the platform requires a Kinect camera, a projection screen, and a computer with MediMoov installed (see Figure 1). The platform allows participants to choose from a range of video games that can be played through different rehabilitation movements involving different parts of the body. This design enables multiple games to be used for a single exercise, and vice versa, with each movement being adjustable to match the user's motor abilities. For instance, a calibration phase is conducted before each gaming session, for each user, to adapt the sensitivity of the game controller to the range of motion and postural abilities of the user (see Figure 1). Furthermore, each participant's profile, containing details like age, gender, calibration parameters, and physical capacities, is used to personalize the gaming experience. The platform offers 14 exercises within 6 games,

which can be adapted to specific conditions and cognitive statuses. The length of each game session can also be adjusted to suit the participant's endurance. Overall, MediMoov offers a solution for motion-based physio-gaming in elderly populations, facilitating motor rehabilitation through an interactive platform. A version based on low-cost RGB camera is currently being developed, and a prototype allowing to handle multiple players simultaneously is being tested on the field.

3 USER FEEDBACK

Currently, the platform is used in over a hundred residential care homes, including rehabilitation centers, retirement homes, hospitals, among others. It is employed by a diverse range of healthcare professionals for various applications and pathologies [10, 24]. Some retirement homes with a healthy elderly population use it specifically for animation purposes, while other residential care homes use it for animation and functional rehabilitation of post-stroke patients [24].

User feedback highlights that the platform is notably easy to install, requiring only a display screen and a Microsoft Kinect v2 sensor, without the need for extra devices or markers. The company not only installs and maintains the platform but also offers training to teach designated staff how to use it effectively.

Users report that MediMoov provides a range of games and exercises. They mention games that focus on sit-to-stand repetitions to enhance strength and balance, while others involve ground plane movements for improved mobility and coordination. Additionally, users appreciate games encouraging simple arm or leg movements while seated, suitable for various mobility and strength levels.

Feedback from users indicates the platform's adaptability to each patient's specific motor abilities. They note that games are playable using different limbs, tailored to individual capabilities. For instance, tetraplegic patients can play using head inclinations, and paraplegic patients can use hand or head movements. Users also value the interface manager that calibrates in-game interaction to the player's motor capabilities, adjusting for motor, sensory, and cognitive abilities.

Users express satisfaction with the platform's engaging games, effective in monitoring and tracking patient performance. They appreciate the non-punitive scoring system based on achievements. The ability to create individual profiles for each user, tracking their performance across games over time, is also highly valued for providing a comprehensive view of development and improvements.

Despite all the positive aspects, users feedback allowed us to identify many areas of improvement:

- Inclusion of new movements, and more particularly fine motor skills movements, involving wrists/hands rotations, fingers flexion/extension, feet/ankle rotations, etc.
- Enhanced motion capture detection for highly disabled users (amputee, persons in wheelchair with total body paralysis).
- Improved motion capture precision, preferably biomechanically accurate, to provide the clinician with the possibility to monitor the patients progress.

These improvements can be done by leveraging state-of-the-art algorithms and methods that are discussed in next section.

4 FUTURE IMPROVEMENTS THROUGH STATE-OF-THE-ART METHODS

As mentioned in the Introduction, the improvements of the MediMoov platform consist in taking into account the user feedback while allowing the interaction with physio-games from a single RGB camera, which is widely accessible. Indeed,

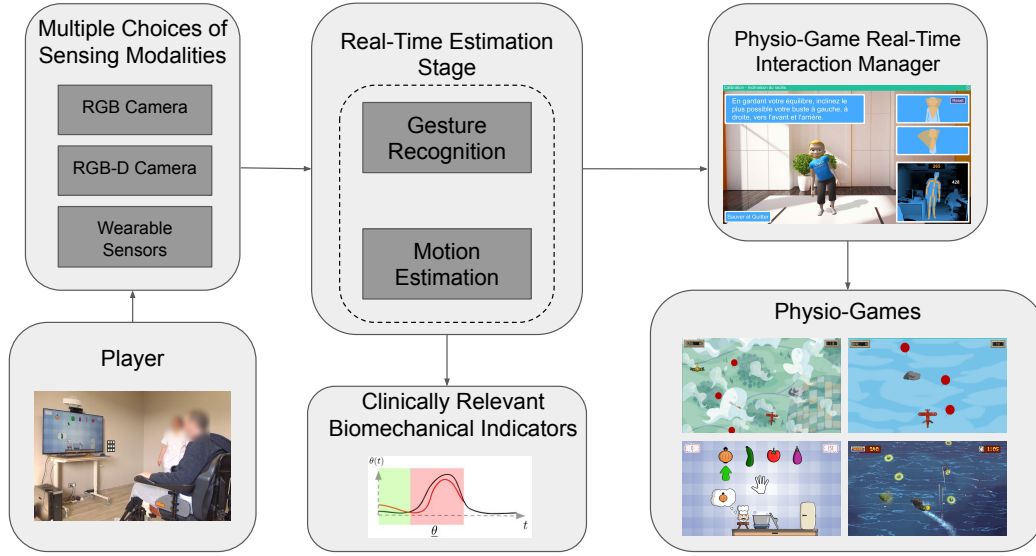


Fig. 2. Flowchart of the New MediMoov Platform Architecture. This diagram illustrates the integration of multiple sensing modalities, real-time gesture recognition and motion estimation. The platform provides clinically relevant biomechanical indicators and manages real-time interaction with physio-games.

the Microsoft Kinect v2 is no longer manufactured, and the other RGB-D sensors that are not as affordable/accessible as an RGB camera. For each point of improvement, we provide literature references that should be investigated.

4.1 Include Fine Motor Skills Movements

Progress in computer vision allow to perform object detection, and also estimate terminal limbs (head, hands, feet) Cartesian positions, in real-time, from a single RGB camera using available open source frameworks such as MediaPipe [14]. A recent study demonstrated the possibility to use MediaPipe pose estimation and gesture recognition algorithms for human-robot interaction through hand gestures [17] and simple RGB camera.

4.2 Enhance Detection and Motion Estimation for Disabled Users

User feedback often reported that some amputee participants or persons in wheelchairs were not able to play with MediMoov, which is highly regrettable. This was systematically due to the inability of the Microsoft Kinect v2 algorithms to detect the person. Indeed, these algorithms trained on healthy human shape morphological models, were not able to generalize to specific morphological cases as amputees, or specific configurations involving pathology-specific wheelchairs.

Recent progresses in human detection and pose estimation from RGB images introduced real-time person detection and joints Cartesian position estimation algorithms robust to body occlusions [4, 14]. On top of that, human computer interaction literature [2, 3] recently introduced methodologies to build personalized interactive systems, based on physiological specificities and motor abilities of disabled persons.

4.3 Provide Accurate Biomechanical Data to the Clinician

Many clinicians demanded to include biomechanical data about the participant's movement, such as spatio-temporal data and joint angles. Recent studies demonstrated that it is not possible to determine joint kinematics from a single camera, that are accurate enough for biomechanical analysis [5]. Approaches providing accurate kinematics estimation either rely on costly multi-camera non-portable systems [8, 9], or on low-cost systems that require one wearable sensor per segment, which can be cumbersome and invasive for disabled persons.

NaturalPad company financed a thesis to develop a device for human motion analysis from a reduced set of sensors. In a recently published work, we introduced a method to accurately estimate joint kinematics by adding wearable sensors to the body extremities [1]. The study demonstrates the possibility to estimate upper limb joint angles by adding low-cost wireless wearable sensors to the hand and trunk, with an accuracy inferior to 10 degrees [1]. The proposed approach is minimally invasive and cost effective, when compared to other methods in the literature that use one wearable sensor per segment [11, 16], or configurations relying on cumbersome multi-camera systems [9].

4.4 FUTURE PLATFORM ARCHITECTURE

The new version of the platform should propose motion-based interaction through one or multiple sensing modalities (RGB camera, wearable sensors). Depending on the available sensing modalities, the platform should provide an adapted motion-based interaction with physio-games and/or provide joint kinematics estimation. For instance: if only the RGB camera is available, the platform should allow a participant to play; if the RGB camera and some wearable sensors are available, the platform should leverage both image data and wearable sensors' data to enhance the quality of interaction, while estimating joints kinematics and providing biomechanical metrics to the clinician. Figure 2 provides flowchart of the platform architecture.

5 CONCLUSION

This article discusses the current state and future evolution of the MediMoov platform, a software tool designed for motor rehabilitation that combines video gaming with physical therapy exercises (physio-gaming), primarily targeting the elderly and persons with physical disabilities. Its recurrent use in various healthcare settings, including rehabilitation centers and retirement homes, has provided considerable user feedback. This feedback highlights several aspects of the platform: ease of installation, a diverse range of games and exercises, and the ability to customize to the user's motor abilities, underscoring its functional utility in a therapeutic context.

However, the current version of the platform depends on the Microsoft Kinect v2 sensor. Additionally, user feedback has indicated the need for including a wider range of movements, particularly finer motor skills, and improving motion capture accuracy, especially for disabled users. Moreover, many clinicians using the MediMoov platform have requested a motion estimation tool that provides biomechanically relevant indicators of the participant's movements. These areas of potential improvement suggest that the integration of state-of-the-art motion estimation, tracking, and gesture recognition methods, adaptable to various sensor modalities, is proposed for the future version of the platform.

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