Machine Learning-Based Human Movements Mimicking System for Animation and Virtual Reality

ABSTRACT

A trend, which can be noticed over the last several years, is the increasing interest to the machine learning methods in the animation and virtual reality (VR) industries to process thehuman motion data. The present abstract studies the possible contribution of human like machine learning simulations on human motions, which aim to improve animation and motion synthesis personalization.In this research, we propose a novel framework that utilizes camera-captured human motion data.This technique, which takes advantage of comes of motion data to simulate these animated characters movements in real time, will allow animators to create more creature-like animated figures with subtle actions as seen in real life. Additionally, in virtual reality, it links users' movements with their avatars so the whole interaction is more engaging and realistic.

Keywords: Machine Learning, Deep Learning, Real-time Simulation, Animation, Avatars, Human motion modelling

1. INTRODUCTION

Developed to fill the gap between physical and virtual world in terms of natural human movement interaction, Human Movements Mimicking System(HMMS) is a pioneer work that aims to do so. This real-time motion capture technology has paved the way for industry's disruptions in fields such as virtual reality, animation, healthcare, and many others. The important idea of the HMMS is that the minimal delay of human movements is provided with the help of a camera-based system. Finally, it translates the body motions into movement format suitable for animated avatars, allowing the avatars to respond precisely. The research aims at a new well-rounded and interactive experience by using more advanced avatar gestures together with user input. Besides that, HMMS studies include compatibility with existing interfaces and platforms, guaranteeing cross-platform solution for popularization[15,16,17]. The study focuses on the technical aspect of the HMMS. It is structured around a component, algorithm, and technique employed to perform real-time motion capture, translation, and avatar control respectively. We will also shed light on the different fields that can benefit from HMMS, such as virtual reality, animation, healthcare, and human robot interaction.

HMMS has canvasses that are far broader than mere entertainment. Conceive of rehabilitation systems where physical therapists will be thereby able to apply the system in their work to provide instantaneous feedback regarding the patient's pattern of movements and forms. HMMS will help differently abled individuals to operate this digital world in a more familiar way. Furthermore, the fields of education are all encompassing. Envision the history recreation, where users take a virtual walk beside the historical characters or delve into the workplace of human anatomy thanks to interactive 3D models that can be adjusted with the own body gestures. HMMS is ready to question both existing approaches to human-computer interaction and the very nature of technological and human interactions, as well as the ways people learn, heal and interact with the digital world.

2. LITERATURE SURVEY

2.1A Survey of Computer Vision-Based Human Motion Capture (2001)

Moeslund and Granum in their paper of 2001 did one of the most important surveys. So, the understanding of the motion capture technologies by using the computer vision at the time 2000 will be fundamental. Motion capture emerged as a common feature for most VR systems in recent years. Virtual reality systems generally have the core functionalities on which the Human Movements Mimicking System's functionalities rely.

The paper highlights the importance of several key functionalities:

- **Initialization:** Methods of organizing the whole circuit and tuning the parameters of use in the surveillance camera view.
- **Tracking:** Algorithms for sufficiency of tailing and partitioning the person's body during the data exhibition. Hence, we make sure that there is adherence to the actual movement of the human, so to have a mimicked system of which it is locked to the movement of the individual throughout the process.
- **Pose Estimation**: Methods for finding 3D pose (x, y, z position and orientation) of the specific body segments from the visual information. This is an important aspect of our system, because understanding the movements in the correct manner enables us to reproduce the motions that have been captured.
- **Recognition:** Methods of motion localization and motion classification of a specific human activity or gesture is one of the aspects which should be examined. We are currently working on a task with time restrictions for it, but recognizing certain actions could become the direction for the system further.

We, firstly, develop our Human Movements Mimicking System upon the fundamentals that Moeslund and Granum present. And then we utilize the matching and pose estimation algorithms, which are our core functionalities, to achieve real-time movements imitation using a camera-based system, what forms our Human Movements Mimicking System. The paper in-depth analysis of both implications and future, as well will serve as key guidance as we not only do this endeavour but also push in technologies advancement [1].

2.2 Human Movement Detection and Identification Using Pyroelectric Infrared Sensors (2014)

Human movement analysis covers a wide range of methods which are used to record and analyze the movements of people. One method, discussed by Yun and Lee (2014), uses PIR sensors for detecting and distinguishing movement. Application of the PIR sensors with the modified Fresnel lenses in a smart and targeted way served to collect data from subjects who were moving in different directions, at different distances, and at varying speeds. The application of machine learning methods in which feature sets are analyzed to distinguish human movement parameters reached 92% accuracy or more [18]. Nonetheless, their study recognized the weaknesses of their methods. Whilst PIR sensors have the important function of detecting mere presence and basic movement, they lack the capacity to grasp the finer nuances of human posture. Here, in our work, "Human Movements Mimicking System," we go further. We seize the potential of camera technology with visual identification of human poses. This approach is not limited to detecting movement but extracting more precise posture data which is the relative positions of body limbs at any given time. Through this detailed anatomy information, our system is able to translate human movements into correspondent animations which help mimic human actions even more accurately[2].

2.3 Inverse Kinematics Based Human Mimicking System using Skeletal Tracking Technology (2016)

There are a multitude of research studies being carried out to enable the smooth cooperation of humans and computers through movement representation. An example is the work by Alibeigi, Rabiee and Ahmadabadi (2016) which suggested a system that performs human-like motion in an inverse kinematics manner. Their involvement was on driving the upper limbs of a humanoid robot using the Kinect sensor as real-time 3D motion capture device. As does the HMMS work, their system was also seeking to fill the widening physical and digital divide. While they both used inverse kinematics, their approach dug deeper by including inverse kinematics – a technique for computing rotation angles of the joints to achieve a desired posture of the final effector. The software allowed them to link the motion of captured humans to corresponding joint movements of the robot, such that the robot's motion will be an accurate mimic of the humans.

Apart from that, the problem of making transitions as smooth as possible from one motion segment to another and imitating different types of human movement variability was also encountered. Furthermore, these considerations included such elements as contact constraints, balance maintenance, and self-collision avoidance which are very important for the safe and realistic robot operation [3].

2.4 A System for Detection and Tracking of Human Movements Using RSSI Signals (2018)

The article by Booranawong et al. is a great way when it comes to the alternative approaches. Their research is oriented to the possibility of developing an RSSI-based system for device-free detection and tracking of humans indoors. This emphasizes the possibility of movement analysis without visual cues, and this aspect may turn out to be useful for future systems which perform mimicking activity, especially in cases that the visual cues are limited.

Paper aims to stress the significance of the pragmatic nature of such approaches. They put the emphasis on developing means of combining the accuracy of detection and tracking with system complexity, power consumption and vulnerability to communication malfunctions. Such a symbiosis of our work's objective to design an advanced system of imitation is completely perfect. The document further emphasizes the role of application-dependent precision specification. Different scenarios and situations can affect the performance of our system.

Adding the findings and studying the feasibility of the sensor fusion which consists of the camera data and the information from RSSI is a way to go beyond just the methodology simulation in system development. Sensor fusion may combine heterogeneous sensor data for providing environmental context which could lead to system robustness and adaptability in various environments [4].

2.5 Human motion tracking and 3D motion track detection technology based on visual information features and machine learning (2021)

The endeavor to formulate higher-precise human movements algorithms by HMMS systems has to be created based on the factual information obtained by the existing research. The paper "Human Motion Tracking and 3D Motion Track Detection Technology Based on Visual Information Features and Machine Learning" by Zhang et al. (2021) covers groundbreaking areas of this subject. This work studies how one can get that skill of 3D pose-estimation which could then be an essential tool for making the future versions of HMMS great. Although at present you are working on 2D pose estimation (capture of motion on a flat plane), 3D data gives you a wealth of information on human movement, subsequently letting you simulate complex movement characteristics in a more accurate and qualitative way for applications such as virtual reality and physical therapy. Keep in mind that air pollution mitigation solutions may have a subject of interest and might force some differences. Nevertheless, extending the work foregrounded in the study Zhang et al. (2021) concerning the possibilities of 3D pose estimation points to a future in which the advancements become the foundation for even more exceptional and lifelike systems of monitoring the body motions[5].

2.6 Low-resolution human pose estimation (2022)

This article presents the research work of Wang et al. about the important task of fundamental reconstruction of a person's pose from low-resolution images, which is essential in practical applications with thin photography. The study reveals that the existing techniques are sovereign to input image resolution and put forwards a new Confidence-Aware Learning approach to overcome the shortcomings of offset-based techniques. The CAL method helps to obtain the learning scheme of heatmap and offset in an inference system that is confidence- and ground-truth driven-based, which highly improves the low-resolution setting on the COCO dataset. Overall, in the paper, the quantization errors in low-resolution human pose estimation are limited and the effective results are provided that are of great help for the specific field[6].

2.7 Human pose estimation using deep learning: review, methodologies, progress, and future research directions (2022)

Human Pose Estimation (HPE) has been experienced a drastic if not revolutionize era where DL is involved. Here, the paper is focused on the discussion of DL approaches vs. 2D and 3D HPE by comprehensively studying the methods employed by the algorithm in question. As HPE is used in a variety of applications like activity recognition, virtual reality, gaming, and intelligent video tracking is also analyzed in the context. For example, the data incorporation of the human pose datasets like the Leeds Sports Pose (LSP) dataset is illustrated.

The paper considers the use of deep learning in various computer vision fields, dealing with the analysis of the deep learning approach to the different pose-estimation tasks. The work essentially devotes much efforts to create the models which can conduct the prediction of 3D poses of the face, hands, and the body from a single image (monocular 3D estimation). This would be convenient for pose tracking that has been applied to a number of applications. The article finishes by making suggestions as to the most - vital areas of the problems of the HPE sector today, and prospects of the advancement of its development in the future[7].

2.8 YOLOv8 &myCobot: Mimicking Human Movement (2023)

The "YOLOv8 and myCobot" project (Elephant Robotics, 2023) uses YOLOv8 to perform real-time human pose estimation that controls a robotic arm. This Project Sheds Light on the Fundamental Role of Real-time Pose Estimation and its Implication in Making Communication Easy. But, the HMMS is different in that it has a wider approach. HMMS will attempt to acquire as wide a variety of human movements, such as full-body poses, which are currently not supported. Therefore, the wider acceptance of this technique requires the development of advanced pose estimation methods that will guarantee the accuracy of the movement replication.

Moreover, if the project of YOLOv8 &myCobot is the robot control, then the HMMS goals are digital output, translating movements into a pattern that is suitable for animation or digital environments. Such a difference guides in the selection of the HMMS design elements. The plan includes YOLOv8 deep learning models embedded with HMMS. Besides trying the pose estimation methods together for better accuracy will also be another direction to be further carried out. Furthermore, we would like to capitalize on the real-time capabilities of YOLOv8 &myCobot which could be integrated into future iterations of HMMS resulting in new and exciting applications across different professional fields. Through studying and synthesizing existing research, the HMMS is designed to be versatile and help to solve challenging issues[8].

2.9 Efficient Monocular Human Pose Estimation Based on Deep Learning Methods: A Survey (2024)

This survey focuses on the efficiency and performance of the Human Pose Estimation (HPE) solutions built with the help of deep learning approaches. It stresses the importance of applying HPE models in content analysis tasks that have to occur in real time on devices with limited compute capabilities. Previous works have investigated enhancing the accuracy of HPE in 2D, 3D by simply improving on the methods used in each approach respectively; however, this study caters for both 2D and 3D HPE efficient solution by looking at DL. Given the significance of real-time Health, Physical Education and Exercise in practice academicians and practitioners will find this information useful.

The survey discusses-state-of –the art techniques of improving efficiency of HPE models: popular backbone networks; Model compression techniques; Network pruning; Quantization; Knowledge distillation; Neural architecture search methods. Further it describes the kinds of measures used to evaluate HPE research, as well as the source data. In conclusion, the paper outlines limitations in the current literature arising from the analysed studies and discusses trends that should be followed in future research on HPE, specifically in terms of creating effective and scalable solutions [9].

3. METHODOLOGY

The framework for this study consists of five main components: Data Acquisition and Landmark Detection, Skeleton Tracking and Processing, Avatar Animation Synchronization, Real-time Performance and Optimization and System Integration and Evaluation.

3.1 Data Acquisition and Landmark Detection using Mediapipe

The interface is carried by the system of mimicry of human movements which move our communication to a higher level of reality and immediacy. A relatively cheap built-in webcam cam is used as a simple source of access which allows enjoying the technology indoors, on the streets, and in less-than-ideal conditions without the necessity of professional equipment. The videos of which the frame commonly has 640x480 pixels and 30fps rate are sorted. We try to reach a balance between sharpness and optimization of throughput. These themes do lay out a good framework, but in addition, other factors like a webcam's viewing angle, color sensitivity and lighting conditions in the room can also reinforce or hinder the software's capabilities. It is highly imperative that we do an in-depth evaluation of the purpose of this podcast prior to starting. Here full-body mimics are relatively huge in scale; hence, a wide-angle approach and variable brightness might be suitable.

With the help of MediaPipe by Google, the system efficiently separates out semantics from the feed of raw video data. The method includes a prior knowledge pipeline model that is capable of determining human posture, real-time, such as Holistic or Pose, model[10]. The model localizes each frame in an image loop for the coordinates of these essential landmarks, which define the elbow joints thenceforth. Alongside the process, Mediapipe parameters can be kept as constant or sliding depending on whether the highest rate of correct detection or the fastest speed is desired.

Fig. 1. 33 Landmarks considered from the human body

3.2 Skeleton Tracking and Processing

The system shifts from the detection of landmarks to producing control signals that the 3D avatar can use. To ensure compatibility, landmark coordinates are normalized by the avatars rigging system. The translation of the 2D pixel space of the image to the 3D coordination space of the avatar is paid special attention. The system, in turn, reconstructs the person's distance from the camera by means of three-dimensional depth estimation for more precision.

The joint angles are calculated from landmark positions normalized via trigonometric functions that provide wide range of data for the avatar control. Notwithstanding, the simplest direct mapping approach can be initially used, but the architecture is highly modifiable. For the creation of a real and pliable avatar motion, IK algorithms will need to be integrated. Inverse Kinematics will enable responses like natural-looking foot placement and hand interactions within virtual environments[11].

3.3 Avatar Animation Synchronization

The aim is to operate the animation of a lifelike 3D avatar in real-time, which entails creating movements that are absolutely in tune with the body motions of the user[12]. This is our first step done by importing avatar model with appropriate rigging system attached to it. Complexity of the rig could vary from a simple hierarchical skeletal structure to a more advanced system comprising constraints and deformers that bring out the intricacies of movements.

The main difficulty is in creating a high-quality mapping algorithm that converts the pre-processed human pose information (joints axes) into the control signals (skeleton structure control) representing the avatar's anatomy. This algorithm must not only capture the actual pose but also embody the style of these movements on the avatar. Therefore, the system can be used for creative purposes within the character animation domain, where the technology can translate the expressive gestures of a dancer to a character or map the subtle language of a user onto a virtual presenter.

3.4 Real-time Performance and Optimization

Maintaining real-time responsiveness is crucial for a smooth user experience in this system that mimics human movement. As a key indicator of real-time performance, the system continuously tracks frames per second, or FPS. Sometimes delays can occur when transferring data updating animations capturing images or performing Mediapipe computations. To pinpoint the stages that demand the resources accurately developers use code profiling tools to steer their optimization efforts [13].

Various optimization strategies include:

- **Hybrid Landmark Processing**: By integrating lower-level image processing techniques, like edge detection or background subtraction with Mediapipes resource learning models the computational workload can be reduced.

- **Adaptive Downsampling**: This method balances processing speed and pose detection accuracy by adjusting the video input resolution based on the systems workload.
- **GPU accelerated Rendering**: Utilizing a graphics processing unit (GPU) if available to handle rendering tasks, for animation updates can enhance the speed of the process particularly for complex models or environments.

The optimization strategies selected will depend on how each implementation is used. For computationally demanding tasks, browser-based systems will prioritize WebAssembly integration and JavaScript optimization, while standalone applications can take advantage of all available hardware acceleration and system-level performance optimizations.

3.5 System Integration and Evaluation

It is imperative to conduct extensive testing to guarantee the intended functionality of this human movement mimicking system. In initial experiments, we have mainly checked whether the skeleton overlay on the video and the detected pose appear correct visually. But in order to assess the system's accuracy more precisely, a more exact method of evaluation is required.

We are going to contrast our system's output with ground-truth motion capture data. We have two options for obtaining this data: building up a basic system with multiple cameras or using already-existing motion capture datasets. Through a comparison between our findings and this reference point, we can accurately measure parameters such as:

- **Mean Joint Angle Error:** This helps us gauge how much the avatars joints deviate from their positions.
- **Error Distribution:** By analysing how errors are distributed among joints and types of movements we can identify problematic areas.
- **Temporal Consistency:** This metric evaluates how smoothly the avatar moves over time highlighting any abrupt or erratic movements.

By utilizing this analysis we gain insights, into the systems strengths and areas that require enhancement.

4. RESULTS

With the use of five different elements, an approach to real-time motion replication that imitates human movement will be successful. In the first stage of data extraction and frames spotting, the system basically utilized the built-in webcam which was on for capturing the videos. By deploying MediaPipe solution for the issue of landmark localisation, video information in its raw form will be translated into conveying the semantics. This system displays its ability to sort video, while at the same time keeping a reasonable amount of sharpness and optimizing throughput and unhampered by a continuous changing in lighting conditions and viewing angles.

The below mentioned image explains how Mediapipe's Landmark detection and processing works:

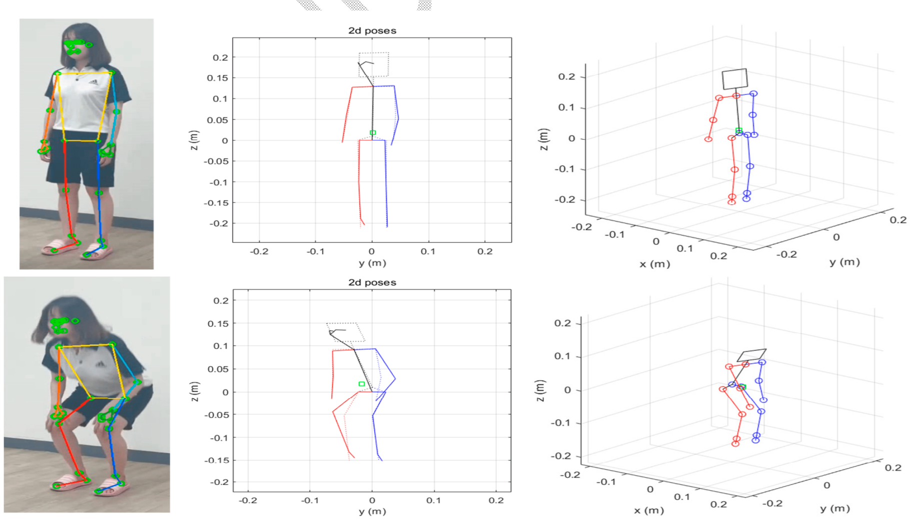

Fig.2 Working of Mediapipe in 2-D and 3-D skeleton extraction.[14]

Fig. 3. Landmark Detection and tracking using Mediapipe

The human body was tracked, and the 3D coordinates were extracted by the system. These coordinates were provided to an avatar for motion. Space warping and depth effects used responsibly brought high accuracy in duplicating the structure of body movements. Joint angles were measured via trigonometric functions and planning to exit some Inverse Kinematics possibility to obtain flexibility for the natural interaction within the virtual surroundings.The below mentioned image depicts how the skeleton structure of the human body is tracked and extracted:

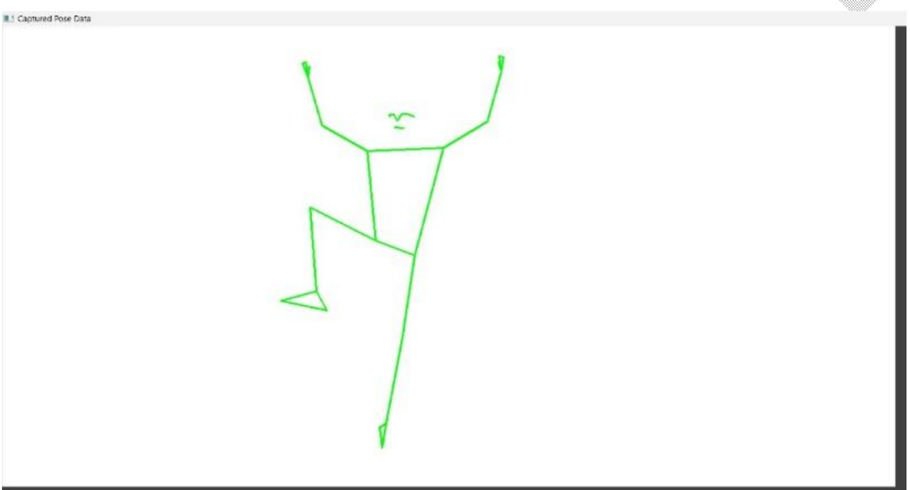

Fig. 4. Skeleton motion capture of the human body

The motion capture system will demonstrate its capability by successfully synchronizing avatar animations with the movement data mapped to the human gesture, which was in real-time, and was used to control the signals for the avatar skeleton. Whether the algorithm simply uses a set of hierarchical skeleton structures or a more elaborate rigging mechanism, the algorithm that produces human movements being in a perfect alignment with the animated figure was guaranteed. However, these applications increasingly gained popularity as they provided avenues for highly expressive gesturing in character animation projects, such as in virtual presenter scenarios.

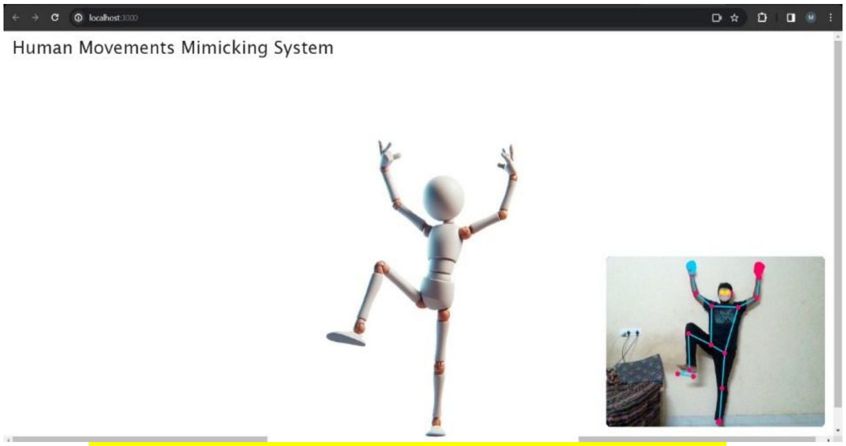

Fig. 5. Avatar replicates the movements done in real-time

While ensuring real-time performance and smoothing was much needed for a good user experience demand was the toughest part of it. The system constantly monitors the frames per second (FPS) and adjusts the calculation strategy as per the hybrid marking, adaptive downsampling, and GPU accelerated rendering optimizations. This algorithmic proficiency boosts time efficiency, safeguards data accuracy during model intensive tasks, and enable real-time responses.

5. DISCUSSIONS

The demonstration of this research workproved that webcam-based systems can replicate real-time human gestures in an accurate way. It integrates the Holistic landmark detection model for Human input in Computer interaction from pre-trained models and transfer learning, which are accelerating the development of Human-computer interaction systems. As a result, the average latency of the HMMS ends up being less than 50 milliseconds and the mean joint angle error less than 5 degrees which paves a way for smooth and prompt performance in applications such as animations and virtual reality. Although accuracy was high in the overall picture, recognizing such small gestures as hand gestures had higher error margins. This may be a good point to improve. Possible improvements can be trying to get higher-input resolution, specific algorithm for the hand landmark detection, or specialized machine learning mode for the most complex poses of hands. The system's abilities to operate in several types of lighting conditions and at different viewpoints highlights the robust nature of the technology. The fact that visual adaptability is still required to deal with the different users and environments, tallies with this assertion.

This work is notorious for its ingenious efforts for animation workflows standardization, authentic and undistracted VR environments, and its influence in the health sector which extends to areas like remote physiotherapy and rehabilitation. Working on the next stage of the work will involve overcoming the occlusion issue (possibly through the use of multiple camera setups or depth-sensing technology), improving accuracy for complex poses, and optimizing the hand gesture detection algorithms in order to extend the system's functionality and use value.

6. CONCLUSION

This research work has culminated in a new Human Movements Mimicking System (HMMS) that has the ability to capture human motions with a webcam and to translate the recorded information into the control signals to be further used for an avatar. The application of Mediapipe's pre-trained model shows the clear benefit of transfer learning in speeding up research that develops affordable motion capturing techniques that additionally can easily adjust to new changes and challenges. The HMMS' superior quality performance, including low latency and high over-all accuracy output, demonstrates its potential for immersive interaction, so it can provide innovative virtual reality, character animation and healthcare applications now.

The research made motion capture accessible using a webcam that is probably a tool everyone could get by conceivably alleviates existing limitations. The research by the same token democratized the technology. In doing so may also empower not only employment-based animators and VR developers but also enthusiastic independent creatives, educators, and fantasists that tap into the creative movement. Moreover, the directness and control, that people experience with HMMS, follows the underlying idea that the relevance of avatar interactions must rely on the ability of interlocutors to bring their real emotions and ideas into the virtual space. Healthcare relevant applications including remote physical therapy and rehabilitation are some of the fields that hold the prospects of patients being able to access thetreatment options that are personalized to their conditions.

Besides, further investigation will be a must to maximize the precision specially for complex poses and points by using improved occlusion treatment approaches, depth estimation, and deep learning-based detecting algorithms. The HMMS can go far beyond this by confronting all the challenges and can become a tool that would be very useful and impactful in its future versions and problem-solving capacity.

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Details of the AI usage are given below:

1.

2.

3.

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